Local Systemic Change projects, funded by the National Science Foundation, were designed to help teachers of mathematics and science deepen their content knowledge and improve their instructional practices. Ms. Weiss and Ms. Pasley describe how these aims were accomplished through a combination of intensive professional development and follow-up support when the teachers took their new knowledge and skills back to the classroom.

BY IRIS R. WEISS AND JOAN D. PASLEY

IN THE FALL of 2001, University of Delaware Professor Jon Manon observed a mathematics lesson about factoring in an eighth-grade classroom of an urban middle school, “a school which is home to what is often reputed to be one of the most challenging student populations in Delaware.” Jenni Green (a pseudonym), the teacher he was observing, had been a participant in an intensive summer institute, and Manon wanted to find out if any of the summer’s workshop lessons had had an effect on her work. “I decided that I would look for a ‘residue’ from the summer professional development across grades and units,” writes Manon in a case study published on LSC-net, an interactive website for the project leaders of the Local Systemic Change (LSC) initiative, funded by the National Science Foundation (NSF) since 1995. “In particular, I was seeking evidence that our emphasis on the instructional model, the launch-investigate-
summarize lesson cycle, was finding root in actual prac-
tice."

A LESSON IN FACTORING

Jenni Green used to teach sixth grade. This year, she was
an eighth-grade mathematics teacher. According to Manon,
"she did have special concerns about particular students,
e.g., one 14-year-old had a baby and often stayed home to
care for it. But when these kids were in school, Jenni was
prepared to help them focus on learning mathematics."

Manon's visit to her classroom came at what Jenni de-
scribed as "a very critical moment" in the Mathematics in
Context curriculum algebra unit, Building Formulas. 3

Manon continues:

This was the lesson in which factoring was first in-
troduced. We agreed that it was a seminal concept,
a gatekeeper to success in a more formal algebra
course. As the name of the unit suggests, building
situations were used to introduce algebraic repre-
sentations. Section B, Basic Patterns, exploited the
context of construction with bricks to introduce a
representation for rows of bricks involving Stand-
ing, S, and Lying, L, bricks. For example, the length
of [a simple] pattern, made up of two Standing
[bricks] and one Lying brick, might be represented
symbolically as $2S + L$.

A basic pattern such as this one might be repeated to
produce a longer string of bricks. And that new configura-
tion might be represented as either three basic groups of
two Standing and one Lying — $3(2S + L)$ — or, dropping
the reference to the basic pattern, as $6S + 3L$.

Before the students arrived, Jenni had described the ap-
proach she planned to take to introduce her lesson. She de-
cided to challenge her students to identify the "basic pat-
ttern" in a longer string and then determine how many times
that basic pattern was repeated. As the first students en-
tered the room, Jenni apparently made up her mind to try
something different.

Seated at the overhead projector, Jenni wrote "$15S + 10L$" and asked, "How can I figure out what the basic pat-
ttern is in this case?" Immediately, Ellen, a diminutive girl in
the front row, answered, "Five . . . it fits into $[15]$ . . . three
times. For 10, it will be 2." Initially caught off guard by both
the promptness and content of Ellen's response, Jenni re-
covered and asked, "So the basic pattern is repeated how
many times?" She drew 15 Standing and 10 Lying bricks

on the overhead and, indicating a basic pattern in the draw-
ing, said, "I'll try to clarify Ellen's thinking . . . for every
three Standing, there are two Lying bricks . . . pretty cool. I
like that Ellen!" Then, looking quite pleased and shifting
her gaze from Ellen to the rest of the class, she said, "Ellen
stole my thunder! She just explained my whole lesson!"

But this was only the beginning of an extended discus-
sion that was to attract interest around the room. Hoping
that this first success was not an anomaly, Jenni continued
the discussion.

Jenni: I have a row in mind with a basic pattern that
will repeat a certain number of times. What I will tell you
is $6S + 3L$ . . . . . What will my basic pattern be?
Kim: LSS.
Jenni: And how many times will that repeat?
Kim: Three times.
Jenni: What will go outside the parentheses? What will
go inside?
Tom: One L and two S.
Ellen: Another way would be . . . $2S + L$.
Lamar: Maybe LSL . . . maybe SSL.
Jenni: Here's another example. My row has $12L + 8S$
[she writes expression on the overhead].
Jerome: $6L + 4S$ . . . twice.
Jenni: What did you do?
Jerome: Distribute the 2.
Jenni: Is there a more basic pattern?
Ellen: Put 4 on the outside! Then $3L + 2S$.
Jerome: That's great!
Dawn: All she did was take that in half!

As this next phase of the lesson began, Jerome turned
to his partner, Dawn, and exclaimed, "This is fun!"

DEBRIEFING THE LESSON

In a subsequent debriefing, Jenni expressed disappoint-
ment that she had not managed a very good wrap-up for
the lesson. But there had been a lot of good mathematics
going on, and she did not want to interrupt the discussion.
Although she was thrilled that her students responded so
enthusiastically and successfully to the prompt of "find my
basic pattern," she was still worried that she had not shown
them how to "pull out" the common factor.

Both Jon Manon and Jenni Green were part of a network
of mathematics and science teachers, researchers, and pro-
fessors who participated in one of 88 Local Systemic Change
Through Teacher Enhancement projects funded by the NSF. 3

The Delaware (6-12) Exemplary Mathematics Curricu-
lum Implementation (DEMCI) project in which Jenni and
Jon participated was a collaboration of the University of Delaware, the Delaware Department of Education, 17 of Delaware's 20 public school districts, and two charter schools.

The chief aim of the LSC program was to encourage large-scale reform in teaching practice. The overall professional development goals of the LSC were similar across projects, including deepening teachers' knowledge of mathematics and science content and helping them become more conversant with the instructional materials they were expected to use in their classrooms. The projects were implemented in a wide variety of contexts, including districts that served high proportions of minority students and English-language learners, and they developed strategies to meet the unique needs of urban, rural, and suburban districts. Across all schools targeted by the LSCs, just over half of the students were from minority groups.

LSC designs for professional development typically included summer institutes of a week or longer, as well as follow-up support during the school year in the form of study groups, classroom demonstrations, and coaching. It was estimated that it would take a teacher three or more years to meet the target of 130 hours of professional development.

In Delaware, professional developers worked in teams: one person, usually a public school educator, focused on pedagogical issues, and the other, typically a university faculty member, looked for opportunities within the context of the lessons to examine mathematics more deeply. Teachers worked together on individual lessons, modeling them and sharing lesson plans. They conducted "lesson studies" to encourage discussion of the difference between traditional lesson planning and designing an approach that allowed the teacher to use open-ended questions with students and to make connections between concepts.

Jon's classroom visit concluded with Jenni's acknowledgment of her struggle — prompted by conversations she had had during the summer institute — to follow her students' lead more effectively, to "let them take me where they're going." And then she added incredulously, "Do you know what? Some of those same students came to class the very next day with basic pattern puzzles they wanted me to solve!"

LSC EVALUATION

As part of the LSC initiative, the NSF supported a 10-year, cross-site evaluation of the LSC projects, which affected 70,000 teachers in roughly 4,000 schools in 467 urban, rural, and suburban districts across the U.S. Conducted by Horizon Research, Inc., the longitudinal study involved training evaluators to collect the same kinds of data at each site, so the results could be aggregated across projects. One of the strengths of this cross-site evaluation was the gathering of data from multiple sources, including observations of both professional development and classroom sessions. Also included in the study were teacher and principal questionnaires and interviews with project staff members and participating teachers. The analyses are based on a great deal of data, including more than 1,600 classroom observations and more than 75,000 teacher questionnaires.

IMPACT ON TEACHERS

The decade of research on the LSC indicates that sustained, content-focused professional development that is built around student instructional materials and involves a critical mass of teachers and other key stakeholders holds great promise. The LSC evaluation data described above suggest that teacher participation in LSC professional development is linked to a number of positive outcomes in mathematics and science instruction, including overall improvement in the quality of lessons; enhanced quality of content presented to students; more frequent use of such investigative practices as engaging in hands-on activities and working on models or simulations; higher-quality questioning and leading of sense-making discussions; and greater intellectual rigor and student engagement.

Changes in classroom practice, which were evident after about 30 hours of professional development, typically increased until about 80 hours, then leveled off. In particular, lessons based on the designated instructional materials and taught by teachers who had participated in LSC professional development were most likely to receive high ratings.

STUDENT ACHIEVEMENT

There is a growing body of evidence regarding the impact of the LSC program on students. Existing LSC project studies, results from a cross-site science achievement study, and data from principal questionnaires and teacher interviews offer some evidence of the LSC's positive impact on students.

For example, the DEMCI evaluation is one of six reviewed by Westat in a preliminary meta-analysis of LSC projects. During 2002-03, a sample of 39 teachers and all of their 2,102 eighth-grade students participated in the study. The demographics of these students and their previous math performance in fifth grade were similar to those statewide. Student data showed that both the quality of instruction and prior math achievement had significant effects on eighth-grade student performance.
NSF did not require LSC projects funded in the program's first four years to examine student achievement outcomes. The emphasis of the early evaluations was the program's impact on teacher practice. Moreover, correlating the different state assessments and student results is a very complex and difficult task and would have required an entirely different protocol for both the LSCs and Horizon Research, Inc.

Some LSC projects, however, did include a design for assessing student impact, and they contracted with outside evaluators to review their data. Here are summaries of two such projects. First, in a four-year summary report written by the Valle Imperial Project in Science (VIPS), an initiative in Imperial County, California, students enrolled in the program were shown to perform much better than their nonparticipating peers on the science section of the Stanford Achievement Test. This inquiry-based science program featured high-quality curricula, sustained professional development, materials support, community and administrative support, and assessment. Of the 22,500 K-6 students in the Imperial Valley, 81% were Hispanic, 11% Caucasian, 5% African American, and 1% each Asian and Native American. VIPS students also had far higher pass rates on district writing tests than did non-VIPS students.

Second, the National Center for Research on Evaluation, Standards, and Student Testing conducted an evaluation of the K-5 LSC Inquiry-Based Science Program in Seattle. This evaluation showed that fifth-grade students in Seattle who had been taught by teachers with at least 7.5 hours of science-writing professional development outperformed other students. In this study, researchers controlled for socioeconomic variables.

TEACHING SCIENCE IN ELEMENTARY SCHOOL

Another significant finding of the 10-year LSC study by Horizon Research, Inc., was that, at the elementary level, participating teachers devoted more time to science instruction. This finding is important, as previous studies of teachers and teaching show that elementary teachers typically spend less than 30 minutes a day on science instruction, far less than the time spent on reading/language arts or mathematics.

A 2002 case study of an LSC project using hands-on science materials illustrates the challenges elementary science teachers face in confronting their own mental models and misconceptions about science. Ann McMahon, a former mechanical engineer and then co-principal investigator of the Renaissance in Science Education (RISE) project in St. Louis, Missouri, examined the effects of a 12-hour professional development course for elementary school teachers.

All of the teachers worked in the same district, where 92% of the students are African American and 72% qualify for free or reduced-price lunch. The focus of the professional development course was a unit called "Electric Circuits," taken from the fourth-grade curriculum Science and Technology for Children.

Because many K-8 teachers do not have the science background or experience to teach inquiry-based curricula, the professional development sessions were designed to encourage teachers to reflect on their own understandings prior to teaching the unit, McMahon says. Teachers worked through activities in the order they would use them in the classroom. Teacher leaders modeled instructional strategies for the group, and content experts supported them in training their peers.

To teach the material in the unit, teachers are expected to understand the meaning of the terms energy, electricity, circuit, electrical current, voltage, conductor, insulator, semiconductor, and diode. "In addition," McMahon continues, "[the unit] presupposes that teachers themselves have an accurate mental model of what happens inside an electric circuit that enables them to lead discussions and field questions during classroom instruction and to draw effective analogies for themselves and their students."

Two questions guided the teachers' professional development sessions: 1) What constitutes an electric circuit? and 2) In a simple circuit that contains a battery, bulb, and connecting wires, why does the bulb light but not the connecting wires? In introducing the teachers to the unit, McMahon also explained research findings regarding common ideas that children have about electricity.

Figure 1 shows students' and teachers' various conceptions of the way circuits work. Many of the alternatives are not consistent with all of the observational evidence that can be explained by the model accepted within the scientific community (D). Model A, for example, cannot explain why two wires, rather than just one, are needed. Nevertheless, the realization that energy is transferred from the bat-
tery, to the bulb, and then out from the bulb as heat and light does make model A attractive.

Later in the course, teachers discussed observations they had made as they conducted the lessons they would be teaching their students. Moreover, each observation served to support or discredit one or more of the common ideas children hold about electricity. The teachers were also encouraged to discuss their own ideas about electricity and to apply their own understanding to observations made during the sessions.

FROM NOVICE TO EXPERT

The vision of LSC was to provide all students with a common set of experiences that lead to major understandings in science. McMahon decided to visit some classrooms in the district conducting the RISE project to see how teachers were using what they were learning in the professional development sessions in their subsequent work with students.

Although each of the three teachers she observed received the same level of support, attended the same professional development workshops, and worked with the same materials, the quality of their instruction varied dramatically.

From observing the teachers in professional development sessions, as well as in their own classrooms, McMahon surmised that their attitudes toward learning science affected their ability to deepen their content knowledge and to effectively teach the unit to students. In the following narratives, each teacher (identified by a pseudonym) displayed a different viewpoint toward teaching the unit on electricity.

Beau's story. Within the first few hours of his professional development session, Beau told McMahon that he found it insulting to his professionalism to do the activities in the unit. He claimed that he had already learned the content and was fully capable of teaching the material by reading the guide and figuring out for himself what he needed to do in class. When McMahon attempted to explain the purpose of the session, which was to include an observation component and was designed to elicit analogies for electrical circuits, he again insisted that he had already experienced elsewhere everything the project could offer. McMahon encouraged Beau to join the teacher leader cadre to share his expertise. He declined. McMahon inquired how Beau would answer the question, “In a simple circuit, why does the bulb light and not the connecting wires?” To Beau, the question was not relevant to the unit, and answering it was a waste of his time. He did not participate in many activities during sessions and was inattentive during group discussions. For the last four hours of formal professional development, he was absent.

Later, McMahon observed Beau's class. Students worked in pairs, following the unit instructions for constructing the different circuits. Beau, the curator (materials manager for this LSC project), and McMahon circulated among the pairs of students as they worked.

"As I talked with students, it was clear that they had performed previous activities and could report the necessary components and arrangements for a complete circuit,” McMahon noted.

Two students asked Beau questions about how the circuits worked. Beau chose not to respond to the questions. He focused on helping students build circuits, make observations, and record them. Beau did not question students, call attention to the special properties of series and parallel circuits, or connect this lesson with previous ones. Beau ended the lesson after students built the circuits and recorded their observations. He did not conduct the sense-making discussion recommended in the teacher's guide, citing lack of time.

Lily's story. Lily eagerly participated in the professional development, asking questions of the session leaders and taking notes throughout the training. She was satisfied that
her experience gave her strategies to improve instruction in her classroom. During McMahon’s observation of her class, her lesson on series and parallel circuits began with a brief review of what the students had done before and how their previous work informed the task in this lesson.

As in Beau’s classroom, students worked in pairs with the provided materials. Lily drew the circuit diagrams on the board, gave instructions, and circulated among the students, questioning them about what they were doing. After students made the required circuits and observations, Lily conducted a discussion comparing the two circuits. Despite her low confidence level during questioning and discussion, her work with the students exhibited key elements of high-quality instruction.

Constance’s story. Constance has advanced degrees in science, and she is willing to provide professional development to her peers. She became intensely involved in the teacher leader training and learned how to teach colleagues who lacked her knowledge base. While she tried to keep an open mind, it was not easy for her to grasp how uncomfortable other teachers could be when they were teaching science. She was still learning how to convey both her content knowledge and pedagogical content knowledge to her colleagues.

McMahon observed Constance in class. She started a lesson in series and parallel circuits by challenging her students to construct circuits that would yield specific observations (e.g., a two-bulb, one-battery circuit in which one can remove one bulb while the other remains lit). Students worked in pairs with the provided materials, making series and parallel circuits that looked different from the pictures in the teacher’s guide but allowed students to make appropriate observations. Constance then asked groups to show the closed paths in each circuit and compare series to parallel circuits.

Constance posed questions that led students to explain their observations and to talk about the uses of each type of circuit in everyday life. Class discussion was conceptually rich and built upon students’ prior experiences. Constance then brought the lesson to appropriate closure.

ATTITUDE MAKES A DIFFERENCE

In assessing the effect of professional development on classroom instruction, McMahon says, “It is apparent that the attitude the participant brings to professional development makes a difference, as does the structure of the professional development.” Of the three teachers described here, the learners ranged in ability from novice to expert. Of the two novices (Beau and Lily), Beau did not perceive himself to be a novice and so closed himself off from any new learning. This made a difference in his classroom instruction. While he was capable of following the instructions in the teacher’s guide competently, he could not help students process their observations and questions in a way that would allow them to connect experiences with meaning.

Lily’s classroom instruction, by contrast, showed as much attention to performing the activities as Beau’s, but she added the sense-making component consistent with what she learned in professional development. Both novices still need to work on improving their content understanding and instructional practices, but Lily is far closer to achieving the project’s vision of effective instruction than is Beau. Constance is an expert learner whose teaching reflects her rich science background and her confidence in her science knowledge. Her instructional strategies revealed experience with observing nature and marshaling evidence to arrive at a conclusion.

McMahon concludes by observing that teachers need help in determining their position along the continuum from novice to expert learner — and they need this help for each unit. Opportunities should be provided during professional development (of leaders and of the general teacher population) for differentiated instruction that produces greater buy-in. The challenge is to match the structure of professional development to the teachers’ real and perceived needs. In doing so, there is a chance to improve attitudes toward professional development as well as to enhance the quality of classroom instruction.

BUILDING SUPPORT FOR REFORM

Both the brick-laying mathematics lesson in Delaware and the electric-circuit lesson in Missouri characterize the approach taken by the LSC initiative to improving the content knowledge and investigative practices of teachers in ways that can influence their work with students. Going beyond the “one-shot” workshop to make time for teachers to have high-quality, ongoing professional development represented a major commitment on the part of the project staff and the districts involved. Although the initiative did not reach its ambitious goal of providing all targeted teachers with 130 hours of professional development, in part because of teacher turnover, just setting such a goal led to greater pressure to go beyond volunteers, and so the project reached larger proportions of mathematics and science teachers than many previous professional development initiatives had done.

The success of the LSC projects was dependent on their capacity to build stakeholder and policy support. Through a variety of strategies, LSCs communicated a vision of high-
quality mathematics and science education to parents, school board members, school administrators, faculty members, and staff. In most LSC projects, cadres of master teachers emerged with strong commitments to sustaining professional development in science and mathematics at the district level. Moreover, establishing partnerships with university faculty members led to collaboration on professional development activities and the development of courses for new and veteran teachers.

Today, notable examples of the impact of the LSC can be found in districts that continue to reserve their staff development days for mathematics and science tied to the curriculum. Other examples of lasting impact include the alignment of teacher evaluation with the district vision for mathematics and science teaching and learning, as well as management systems created by districts to distribute and replenish the curriculum materials and accompanying kits needed for instruction.

“We think of ourselves as a coordinated system, serving the schools,” wrote one district administrator who was involved with a K-8 science LSC. That represents “a whole different way” for the system to operate.

3. NSF funded the first cohort of LSC projects in 1995, and a new cohort of projects was added each year. By 2002, a total of 88 projects across the country had received funding, typically for a period of five years.
5. Ibid., pp. 62-65.
11. Science and Technology for Children is marketed by the Carolina Biological Supply Company, Burlington, N.C.
12. The RISE LSC provided each school with a building curator, who assisted the teacher with materials management for science lessons.

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