The Science Training

Research suggests that effective professional development in science instruction should focus on four crucial skill sets.

Harold Wenglinsky and Samuel C. Silverstein

Science education in the United States is in serious trouble. On the 2005 National Assessment of Educational Progress (NAEP) science exam, 4th graders were the only group of students who made progress. Eighth graders' performance remained stagnant, and that of 12th graders declined (National Center for Education Statistics, 2006a). International comparisons confirm the problem: Although U.S. students perform close to the international average in life sciences, they lag behind other countries' students in chemistry, physics, and earth science (National Center for Education Statistics, 2003).

Of the many steps needed to improve U.S. science education, none is more important than improving teacher training and preparation. Individual classroom teachers determine the quality of instruction that students receive. Many studies show a close correlation between student achievement in science and teacher preparation in science. For example, using longitudinal data, Monk (1994) found that the best predictor of student performance in science was teacher course-taking patterns: The more science courses teachers had taken in college, the better their students performed.

At first glance, U.S. teachers seem well prepared academically. Almost all U.S. public school teachers have a bachelor's degree, and 42 percent have a master's degree (National Center for Education Statistics, 2006b). What accounts, then, for the relatively poor science performance of U.S. students?

One reason is that too many science classes are taught by teachers who have inadequate preparation in the subject. Ingersoll (2003) found that in 1999–2000, 43 percent of public school life science classes and 59 percent of physical science classes in grades 7–12 were taught by teachers without an academic major or minor in those subjects.

But even if schools could ensure that all science classes were taught by teachers who had majored or minored in the subjects they taught, we have no evidence that such an effort would
guarantee exemplary science instruction. Even teachers who are highly prepared to teach their subjects need ongoing professional development that enables them to refine their skills. The programs described here provide substantial evidence that well-formulated and sustained professional development programs for teachers can significantly improve student achievement in science.

What Science Teachers Should Know
Research points to the essential ingredients of effective professional development in science. An analysis of the performance of more than 7,700 8th grade students on the 1996 NAEP science exam, along with their teachers’ responses to a NAEP survey of teaching practices (Wenglinsky, 2000), found that student scores tended to be higher when the teachers’ professional development experience included significant training in four areas:

- **Laboratory skills.** Overall, students whose teachers had received professional development in laboratory skills scored nearly one-half a grade level above students whose teachers lacked such training. Teachers with laboratory skills training were more likely to avoid cookbook laboratory exercises and encourage their students to make connections between laboratory experiences and underlying scientific concepts.
Many studies show a close correlation between student achievement in science and teacher preparation in science.

- **Hands-on learning.** Students whose teachers had been trained to engage them in classroom exercises and projects that involve physical activity—such as building a functional, propeller-driven airplane—did better on the NAEP science assessment than students whose teachers lacked such training. Overall, students exposed to hands-on science activities once a week were 40 percent of a grade level further ahead in science than students exposed to such exercises only once a month.

- **Instructional technology.** Within the classroom, students cannot view a volcanic eruption firsthand or peer through an electron microscope. But by using the Internet creatively, teachers can enable students to observe eruptions and experience how it feels to use sophisticated research instruments. Students whose teachers used such technology in the classroom performed better on the NAEP science assessment than their counterparts in other classrooms did (Wenglinsky, 2005).

- **Frequent formative assessment.** Students whose teachers administered weekly point-in-time multiple-choice and short-answer assessments were nearly a full grade level (90 percent) ahead of students exposed to such tests less frequently.

The statistical significance of these findings is sufficiently robust to justify pilot studies of the effects of teacher professional development that supports these four practices. Columbia University's Summer Research Program for Secondary School Science Teachers recently conducted such a study.

**The Summer Research Program**
Columbia's program, initiated in 1990, enrolls 10–12 new participants each summer. The program selects teachers
on the basis of a demonstrated commitment to teaching (for example, sponsoring a science club); creativity (for example, implementing a new curriculum); and resourcefulness (for example, creating a lab in a school that does not have one). Participating teachers receive appointments as visiting scholars and conduct full-time research in Columbia University laboratories under the mentorship of university faculty members for eight weeks during two consecutive summers. The two-summer requirement is designed to strengthen the commitment of both the students and the university faculty members who work with them.

Teachers receive a stipend of $6,000 each summer and an additional $1,000 in classroom enrichment funds following each summer of participation. The enrichment funds help the teachers transfer the concepts that they learn at Columbia to their classrooms and students by giving their students firsthand experience with the tools of contemporary science, such as electrophoresis equipment, spectrophotometers, and microscopes. Teachers also receive a Columbia University library card and a modem/network card that enables them to connect their classroom computer to the Internet.

Teachers work in laboratories in all science departments at the university. Each teacher works with a different faculty mentor on a scientific problem. Through this experience, each teacher acquires in-depth knowledge and expertise in certain aspects of a specific scientific discipline (for example organic chemistry, molecular biology, oceanography, or astrophysics) and masters several technologies employed in that discipline. All teachers are treated as professionals. They are challenged to think independently and creatively as they engage in the study of authentic contemporary scientific problems. These experiences stretch teachers intellectually and personally and give them a deeper understanding of how successful scientists practice science.

Teachers meet weekly as a group for seminars and professional development exercises to help them incorporate the concepts, skills, and technologies learned at Columbia into their classrooms. For example, a data analysis seminar trains teachers to use standardized test results for formative and normative purposes. In their weekly meetings, teachers also network with one another. By the end of each summer, they have established a professional learning community.

The program also provides funds to enable Columbia graduate students and postdoctoral fellows who have worked with the teachers during the summer to visit the teachers' home schools each month. Through these school visits, along with telephone consultations and e-mails, the graduate students and fellows help teachers design and implement hands-on exercises in their classes. They also serve as role models for students, many of whom have never met a scientist.

**Evidence of Improved Teaching and Learning**

From its inception, the Summer Research Program for Secondary School Science Teachers has strongly emphasized program evaluation. This evaluation confirms that the program has a
positive effect on teachers and their students.

Teachers who participate in the program undertake more constructivist practices when they return to their schools. They have a better understanding of their students' difficulties because of the challenges they themselves experienced in adapting to a research environment. They also change the ways they respond to students. They no longer call students' responses to questions "right" or "wrong"; instead, they ask, "Why do you think that?" They acknowledge their own uncertainty by saying, "That's a good question. I don't know the answer, but I can tell you how we can find out."

Teachers who have taken part in the program are also much less likely to leave teaching than are nonparticipating teachers. Over the life of the program, fewer than 5 percent of all program participants have left education, compared with an annual attrition rate of 15 percent for science teachers in general (Weisbaum & Huang, 2001).

Students also benefit from their teachers' participation in the program. In the academic year following completion of the program, participating teachers' students are two and one-half times more likely to undertake a project for a national science competition, and nearly four times more likely to participate in school science clubs, than are students of nonparticipating teachers in the same schools. Most important, in the academic year following teacher completion of the program, 7–8 percent more of their students pass the New York State Regents exam in science than do other teachers' students in the same schools. Studies in progress suggest that these positive effects persist for at least two years after teachers complete the program. It is possible that one in-depth experience in the practice of science can change an entire teaching career.

These findings regarding Columbia's Summer Research Program confirm the conclusions of the analysis of 1996 NAEP science results: Professional development that focuses on improving teachers' laboratory skills and stimulating them to implement more hands-on, constructivist practices in their classrooms and laboratories can significantly improve student achievement in science. But despite these encouraging findings, it is premature to conclude that professional development programs emphasizing these principles will routinely produce similar outcomes. More research is required—ideally rigorous, randomized, controlled trials.

One such effort is now underway in Alabama, where the state department of education is conducting an ongoing...
study of the Alabama Math, Science, and Technology Initiative. Hundreds of Alabama schools have participated in this initiative since 2002. Its key activity is a two-week summer institute at which all teachers in participating schools learn how to implement hands-on activities, effectively facilitate student laboratory work, use instructional technology to enrich and enliven the study of such topics as soil erosion, and link all of this hands-on work to higher-order thinking.

Preliminary evaluations show that students in participating schools are performing better in math and science than their counterparts in nonparticipating schools (Alabama Math, Science, and Technology Initiative, 2006). The Alabama Department of Education is now conducting an evidence-based evaluation that has identified 20 pairs of roughly comparable schools and randomly designated one school in each pair as a participant in the initiative and one as part of a control group. The results of this methodologically robust evaluation will provide solid evidence about whether similar professional development initiatives hold promise for raising science and mathematics achievement.

Evaluating Professional Development in Science

In the future, we hope to see further evidence-based evaluations of the effects of science teacher professional development. Such research can empirically verify the effects of a menu of professional development activities. Although the four key components of effective science teaching identified in the analysis of 1996 NAEP data—laboratory skills, hands-on learning, use of instructional technology, and frequent formative assessment—provide a foundation for such professional development, specific programs should emphasize some components more heavily than others, depending on school-specific factors, such as existing laboratory and technology resources as well as teacher expertise.

Development and dissemination of empirically verified professional development programs for science teachers can improve the performance of the present generation of teachers and increase their students' interest and achievement in science. Federal and state governments could play key roles in this process by including laboratory skills in science standards and by providing long-term financial support for demonstrably effective professional development programs. If such support leads to improvement in student academic achievement, the resources invested will be repaid many times over.

References


Harold Wenglinsky is Research Associate, National Center on Addiction and Substance Abuse, 633 Third Ave., Newark, NY 10017; 212-841-5248; hwenglinsky@casacolumbia.org. Samuel C. Silverstein is John C. Dalton Professor and Chairman of the Department of Physiology and Cellular Biophysics, Columbia University, and Founder and Director of the Summer Research Program for Secondary School Science Teachers.