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Professional Development for Science Teachers

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own classroom have had to leave it to become administrators, district leaders, or policy-makers.

The Coming Age of Teacherpreneurs

America's public education system needs teacherpreneurs—classroom experts who teach students regularly, but also have time, space, and reward to spread their ideas and practices to colleagues as well as administrators, policy-makers, parents, and community leaders. The Center for Teaching Quality has supported as well as documented how this special brand of teacher leaders has begun to serve as online coaches, edugame developers, community organizers, and policy analysts, without leaving the classroom (*14*). In doing so, they have begun to solve problems of student and teacher learning that today's reformers have yet to identify. Daunting barriers remain, including the relatively large number of educators in school systems who never teach, the highly prescriptive teaching day, and top-down reformers whose political agendas are out of sync with the ideas of classroom experts. However, teacherpreneurs, because of their deep knowledge of students, families, and communities, are more likely to be embraced by their colleagues.

I am optimistic. Most Americans have trust and confidence in individual teachers (*15*), and new technologies that amplify teachers' collective wisdom and the impact of their leadership will resonate with parents and the public. Additionally, MetLife's most recent survey revealed that one in four teachers nationwide are extremely or very interested in hybrid roles that would allow them to both teach and lead outside their schools, districts, and states (*16*).

While these classroom experts should be highly paid, teacherpreneurship is not mainly about establishing a new income stream for underpaid professionals. It is much more about rewarding a new culture of schooling and creativity. As Peter Drucker said of entrepreneurs almost 50 years ago, "search for change, respond to it and exploit opportunities (*17*)." It is time for America to cultivate teacherpreneurs who will do the same, deepening and spreading best policies and practices for 21st-century teaching and learning.

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REVIEW

Professional Development for Science Teachers

Suzanne M. Wilson

The Next Generation Science Standards will require large-scale professional development (PD) for all science teachers. Existing research on effective teacher PD suggests factors that are associated with substantial changes in teacher knowledge and practice, as well as students' science achievement. But the complexity of the U.S. educational system continues to thwart the search for a straightforward answer to the question of how to support teachers. Interventions that take a systemic approach to reform hold promise for improving PD effectiveness.

Calls for improving science education in the United States, such as raising standards for all children and focusing the curriculum, are loud and clear. The Next Generation Science Standards (NGSS) [www.nextgenscience.org (*1*)] press for a vision of science teaching that emphasizes students' active engagement in genuine scientific problems, a commitment to "less is more," and an approach to make science appealing to all students. Of central importance are scientific practices and the integration of students' learning of core disciplinary concepts with active engagement in doing science (*2*). In addition, an increased emphasis on studying engineering is integrated throughout this new vision of science teaching and learning. Helping current teachers acquire the knowledge, skill, and will to meet these new standards is a daunting enterprise requiring large-scale professional development (PD) of high quality that is adaptable across myriad contexts.

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Teachers in the United States have access to a wealth of PD opportunities, including summer institutes, coaching, mentoring, school-based professional learning communities, research experiences with practicing scientists, and "make-and-take" events that introduce teachers to new materials. Teachers study together, conduct inquiries, read research, learn new technologies, navigate multimedia environments, and read cases. These PD programs have different goals: Traditionally, much PD has focused on enriching teachers' content knowledge (CK), introducing new curriculum and instructional materials, enhancing pedagogical CK, or educating them about scientific inquiry. The U.S. PD system is a carnival of options.

Research on Science PD

Carefully designed research, drawing from a range of disciplinary approaches from ethnographies to randomized clinical trials, has begun to shed light on what makes for effective PD. Five general characteristics have been identified: (i) focusing on specific content, (ii) engaging teachers in active learning, and (iii) enabling the collective participation of teachers (sometimes administrators), as well as (iv) coherence (aligned with other school policy and practice) and (v) sufficient duration (both in intensity and contact hours) (*3*–*6*).

Researchers have nominated five additional factors for effective PD: (i) activities are close to practice (*7*), (ii) participants' physical and psychological comfort is taken into account (*8*), (iii) teachers are immersed in inquiry experiences and witness models of inquiry teaching (*6*), (iv) curriculum materials are educative for teachers and students (*9*, *10*), and (v) teachers receive direct instruction in the teaching specified in innovative materials (*11*). Repeatedly, the importance of strong principal support is emphasized (*12*).

Recently, there has been an effort to test these "best practices" with rigorous research. Here, I consider meticulously peer-reviewed literature. The U.S. Department of Education funded two clinical trials to examine the effects of PD in mathematics and literacy. One of these trials examined the impact of two research-based PD interventions for reading: (i) a content-focused teacher institute series that began in the summer and continued over the school year and (ii) the same institute series plus in-school coaching (*13*). The sample included 90 schools in six districts (270 teachers), with equal numbers of schools in each district randomly assigned to one of the two treatments or to the control group, which participated only in the usual district PD. Teachers in treatment schools scored significantly higher on the teacher knowledge test than did teachers in control schools; teachers in the treatment schools also used explicit instruction more often. However, neither PD intervention resulted in significantly higher student test scores, and there was no additional benefit of the PD enhanced by the coaching. One year later, there were no major lasting effects on teacher or student outcomes. Similar results were found in a study of PD for mathematics teachers (*14*).

A handful of experimental studies have focused on science-specific PD. Using a randomized experimental design in 39 school districts in six states, researchers compared the effects of three systematically varied teacher interventions that are common forms of PD—teaching cases, looking at student work, and metacognitive analysis (as well as "business as usual" as a control condition)—on teacher and student science CK (*15*). Participating districts had to be well established and stable, with strong science leadership; 270 elementary teachers and 7000 students participated in the study. Each intervention involved a 14-week electric circuits course offered in 3-hour sessions. Hierarchical linear models were fitted to gain scores from pre- to posttest for students and from pretest to follow-up test for teachers. Separate models analyzed teacher and student outcomes. Researchers found that each PD course significantly increased teacher and student science test scores, and the effects held one year later. However, only PD that involved teachers examining student thinking and considering the implications for instruction was associated with increases in both teacher and student science knowledge.

In the Science Teachers Learning through Lesson Analysis (STeLLA) project, teachers participated in PD that involved analyzing science teaching practice using video cases (*16*). Two groups of elementary teachers participated in a 3-week PD summer institute (SI) designed to enhance their CK. The STeLLA group ($n = 32$ participants) also analyzed video cases during the SI and throughout the school year. Sixteen teachers participated in the content-focused SI only. The program substantially improved teachers' CK and their ability to analyze science teaching. Students of STeLLA teachers also demonstrated considerably higher gains in their science CK. Teachers who participated in the content-only SI demonstrated initial gains in CK immediately after the summer but were unable to maintain those gains through the school year.

In another study, researchers conducted an efficacy study of three PD programs in a large urban district: investigating Earth sciences, Earth sciences by design, and a hybrid of the two (*11*). Teachers experienced one of four conditions that differed along two dimensions: (i) whether teachers experienced PD that provided guidance in selecting relevant curricular materials and included inquiry-oriented instruction and (ii) whether teachers received PD that included direct instruction in teaching practices. Researchers found that PD with direct instruction in teaching practices can increase students' knowledge of Earth science, but there were mixed results concerning the claim that helping teachers select curriculum that is coherently aligned with standards and includes inquiry-oriented activities will lead to increased student learning.

Although there are a growing number of research studies that examine the effectiveness of the five features of PD described above, the evidence is uneven, and we lack clear direction. Why the uneven empirical base? If no curriculum is teacher-proof, it seems obvious that no curriculum is context-proof: Resources, students, leadership, and teacher knowledge shape an intervention's implementation. Even when interventions are implemented with high fidelity, schools are subject to forces beyond researchers' control. District leadership churns, new curriculum and assessments arrive, policies change, and resources are cut. These factors vex researchers who need to control these changes as much as possible.

Another reason for the uneven research base is that we lack sound measures of teachers' knowledge of science for the classroom, as well as aligned measures of students' understanding represented in the NGSS. Currently available measures of student learning focus largely on the mastery of scientific facts but do not assess students' conceptual understanding or their abilities to engage in scientific practices, which are the foci of much PD.

A third issue is that much PD does not identify specific instructional practices that teachers can master, nor are teachers given the time and structures needed for repeated practice and sufficient reflection (*17*). Instead, teachers learn about general approaches to instruction and take those ideas back to their classrooms, where they may (or may not) try to implement some of these methods. In one study, researchers found that two PD programs focusing on scientific inquiry led to changes in teachers' practice, but the experimental impacts corresponded to the features of scientific inquiry that the teachers were exposed to the most (*18*). Both PD programs emphasized questioning and gathering evidence, but neither effort uniformly engaged teachers in other clearly specified features of inquiry, such as formulating and justifying explanations and connecting those explanations to scientific knowledge. Most troubling was the finding that students in one program had lower standardized test scores than students in a control group in the first year of the study. Researchers hypothesized that learning to ask scientific questions and gather evidence without connecting those activities back to scientific explanations and concepts might leave students and teachers more confused than before. An alternative explanation might be that PD that fails to clearly explicate different aspects of an instructional regime in detail—and to provide sufficient opportunity for repeated practice with focused feedback—will be less effective.

Additionally, researchers lack a clear theory of the underlying mechanisms involved in teacher learning. For instance, researchers have argued that teachers' increased CK leads to better self-efficacy (*19*). In turn, this increased efficacy leads to higher levels of persistence. Thus, teachers who increase their CK also improve their confidence, which leads to more motivation and perseverance as teachers learn to educate in fundamentally different ways. The five general characteristics listed above—duration, active learning, collective participation, coherence, and content focus—are design features, but future research will need to explore how these features work together to produce teacher learning. Using the above example, does a focus on content lead to greater teacher confidence, which, in turn, leads to greater active engagement and, eventually, higher student achievement?

A more complex view of teacher learning is clearly needed, one in which professional learning is seen as more dynamic and iterative, connecting teachers' experiences in their classrooms with formal opportunities for collective reflection and for acquiring new knowledge that targets genuine problems of practice (*17*). Models of teacher learning should also account for the internal coherence of a school's leadership, culture, curriculum, assessments, and PD, as teachers learn inside of organizations that fundamentally shape their interests in and abilities to learn from practice (*20*).

Although researchers have identified several features of effective PD, rigorous research has yet to produce conclusive support for those characteristics. Problems include a lack of sound measures and a strong theoretical understanding of the mechanisms of teacher learning.

PD Embedded in School Reform

An understanding of how PD fits into the educational system's larger ecology is also needed. PD may be best understood as nested within an environment that includes schools (which have their own cultures and norms), districts (which have their own leadership and capacity), students and their families (who have their own backgrounds and expectations), teachers (who have their own knowledge and experience), and curricular materials and other resources. This view has led reformers to create education reform efforts that take a systems approach to improvement, considering leadership, curricula and assessments, PD, organizational infrastructure, and human and social capital. In a longitudinal study of school change, one research team identified five supports for change: (i) leadership (principals who are strategic, focused on instruction, and inclusive), (ii) professional capacity (teacher quality, their beliefs about change, their capacity to work collaboratively, and the quality of ongoing professional development), (iii) parent-community ties (schools that are welcoming to parents and have strong connections to local institutions), (iv) student-centered learning environments (schools that are safe, nurturing, stimulating, and welcoming), and (v) instructional guidance (the organization of the curriculum, its academic rigor, and the tools teachers have to advance learning) (*21*). The researchers found that the real value of these supports was in their combined strength: Schools with strength in three to five of these supports were 10 times more likely to demonstrate significant learning gains (as measured in mathematics and reading).

Initiatives that take a systemic view of educational improvement present challenges to those who want to draw causal conclusions about the contributions of specific components of the reform to student learning. Teachers' knowledge and perceptions, administrative support, PD, and available resources, among other factors, are intertwined with student experiences with inquiry, teachers' collaborations, technology use, and other aspects of the system. It is nearly impossible to isolate the effects of PD on student learning.

Pressing Challenges

Going to scale with effective PD for the entire teacher workforce of 3.7 million will require more research. We face several looming challenges: preparing educators to teach the NGSS, meeting the needs of English-language learners (ELLs), and harnessing new communication technologies to produce quality online science-specific PD that is both effective and widely available.

The NGSS present a view of science teaching that differs from the standard fare in U.S. classrooms. Getting from here to there will require considerable investment of resources: The research described here required considerable development of highly specified instructional materials and tools to support teachers and students in using those materials; additionally, this research validated ongoing assessments of learning and responsive, extensive PD. Responding to the NGSS will require the development of many more such resources, and this innovation will need a coordinated system of research to empirically document the hallmarks of effective instruction, the qualities of effective materials, and the dynamics of high-quality PD. Although the array of available PD in this country is extraordinary, we cannot afford such broad experimentation without learning from it so that we can much better align the resources spent on PD (estimates range from $1 billion to $4 billion per year) with the demands teachers face in today's classrooms.

We especially cannot afford the high cost of experimentation, given the changing U.S. demographics. At least 21% of our students are ELLs, and helping them engage in science is a pressing problem for all K-12 science teachers. Only 2% of eighth-grade ELLs achieved at or above proficiency levels on the 2009 National Assessment of Educational Progress in science (compared with 32% of English-speaking students) (*22*). Only 12% of practicing teachers reported that they had any training in teaching ELLs. The percentages are probably much lower for teachers who have had PD in teaching science to ELLs.

Recent research has begun to explore this challenge by offering PD that integrates learning science and literacy. One such intervention focused on promoting the learning of science inquiry by students from linguistically and culturally diverse backgrounds (*23*). The study investigated the impact of an inquiry-based intervention on students' ability to conduct inquiry. The intervention involved units for grade 3 (measurement and matter) and grade 4 (water cycle and weather). Across the year, teachers attended four full-day workshops that covered scientific inquiry, instructional scaffolding, and balancing teacher guidance and student initiative. Teachers worked on unit plans, demonstrated lessons, and shared ideas. Other workshop topics included incorporating students' home languages and cultures into instruction, as well as incorporating language and literacy into science. Seven teachers in six elementary schools in a large urban district participated in a field study that investigated the PD's effects on students' understanding of inquiry. Researchers documented a significant growth in students' understanding of inquiry from pre- to posttest. In another project, researchers found that when teachers participated in a 3-year effort to provide both curriculum materials and PD designed to improve teaching practices, the science achievement scores of third- to fifth-graders were significantly raised, and achievement gaps among demographic subgroups decreased consistently for third- and fifth-graders and held steady for fourth-graders (*24*). Other researchers report on a quasi-experimental study of a science intervention that targeted ELLs and low–socioeconomic status non-ELLs (*25*). Students who participated in the treatment classrooms demonstrated significantly higher achievement on district benchmark tests in science and reading, as well as on the state reading exam, but not on state science tests.

Another challenge concerns the accessibility of high-quality PD. In a recent survey, the majority of science teachers reported that they were provided more opportunities for generic PD than science-specific PD (*24*). In this case, new technologies might hold promise. Online PD has the potential for providing "just-in-time assistance" and is potentially more scalable than PD that presses on limited local resources. In addition to online courses, other emerging environments—such as multi-user virtual environments in which the participants take on avatars in virtual worlds, augmented realities in which participants in their own real-world contexts interact with a virtual setting, and social networks that connect teachers across the country—also hold promise for increasing teachers' access to relevant, high-quality science PD and materials (*26*). To date, not enough research exists

Grand Challenges

Identify the underlying mechanisms that make some teacher professional development (PD) programs more effective than others. Rigorous research on effective PD for science teachers is gradually accumulating, but we need a stronger theoretical base that reflects the complex ecology in which teachers work and learn. We also need better measures and interventions that are more highly specified to meet particular teacher needs.

Identify the kind of PD that will best prepare teachers to meet the challenges of the Next Generation Science Standards (NGSS). The NGSS specify an entirely new way of teaching science in the United States. It will require a considerable investment of resources to develop appropriate instructional materials and the tools needed to support teachers and students in using those materials. We must realign the considerable resources spent on PD with the demands teachers will face in a NGSS classroom, and we cannot afford such broad experimentation without funding the research required to learn from it.

Harness new technologies and social media to make high-quality science PD available to all teachers. Online PD has the potential for providing "just-in-time assistance," and it is potentially more scalable than PD that relies on limited local resources. To date, there exists little research to help us understand the affordances and limits of these venues.

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In sum, rigorous research on effective PD for science teachers is gradually accumulating, but we need a stronger theoretical base that reflects the complex ecology in which teachers work and learn. We also need better measures and interventions that are more highly specified. Though some might hope for a silver bullet, education reform that leads to fundamental change, such as that envisioned in the NGSS, requires time [it takes several years for teachers to change their practice (*6*, *27*, *28*)]. Reform efforts also require investments in infrastructure (leadership, teacher networks, planning time), the organizational coherence that encourages teachers to take risks and learn new content, parents to support the new standards, and students to demonstrate the perseverance and curiosity needed to achieve scientific literacy.

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PERSPECTIVE

A Business View on U.S. Education

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Business leaders depend on an education system capable of providing a workforce able to compete in a global marketplace. As a partner in education reform, the business community advocates for an increased focus on helping schools connect students more effectively to the world of work through hands-on problem-solving activities and practical experiences.

Government leaders recognize that being poorly educated is tied to unemployment, poverty, crime rates, and spiraling social services costs. Parents recognize that a quality education is key to their children's future. Teachers and educators view their students' success as key to their life's work. Business leaders seek a workforce that can compete in a global marketplace at a time when many jobs cannot be filled for a lack of qualified workers (*1*). Thirty years ago, the U.S. National Commission on Excellence in Education stated that "Our society and its educational institutions seem to have lost sight of the basic purposes of schooling and of the high expectations and disciplined effort needed to attain them" (*2*). Although modest progress has been made since then, the world has been changing faster than its education systems. We believe business leaders would argue that many reform efforts have not yet focused on the right issues.

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In the past 2 years, the Boeing Company has hired 33,000 new employees, and we observe two important phenomena. First, these new employees, from those lacking a high school diploma to those with a college degree, are generally quite good at using digital tools. Second, many seem to have rarely been put in situations where they have had to use their knowledge and skills to create a product of value. Those we hire have lots of ideas and can be savvy about many aspects of information technology. But those who haven't had to relate to a real-world experience of building something, or worked in a situation where failure is a real possibility, will generally need to spend considerable time on remedial training activities. For example, Boeing must now spend 13 weeks training employees for the same manufacturing jobs that used to require half the time; but even then, the employee often remains weak in the skills needed to manipulate materials effectively.

We believe the above observation is common among business leaders, spanning many business sectors. Although more is required from an education than preparing students for the world of work, such findings have important implications for education reform. Today, when students are not in the classroom, they may spend up to 12 or more hours per day using some form of electronic media, whether sending text messages by cell phone, watching TV, or engrossed in using a computer, with yet unclear impacts on learning and problem solving (*3*). While greater use of technology in and out of the classroom holds promise and should be explored, we consider it unlikely that computers and simulations will fully substitute for real experiences in which students manipulate materials and engage in problem-solving in groups.

The classroom therefore needs to be a place where students spend a substantial amount of time applying what they learn to solving relevant problems that are appropriate to their age. As stated by the Ministry of Education of Singapore, teaching should "encourage a spirit of innovation and enterprise in students, and nurture intellectual curiosity, passion, and courage to try new and untested routes (*4*)."

We suggest that businesses focus on helping schools connect students more effectively to the world of work. In the United States, new synergies with industry arise from the recently adopted Common Core standards in English Language Arts and Mathematics, plus the forthcoming Next Generation Science Standards (NGSS), which stress in-class discourse, explanation, argumentation, reading and writing informational text, and active problem-solving (*5*, *6*) [see page 276 in (*7*)].

The NGSS aim to incorporate real experiences into the classroom. But, as highlighted elsewhere in this issue [see page 320 in (*8*)], if we end up using inexpensive standardized assessments that mainly test for factual recall, the standards movement will simply prolong our failure.