Title:
School Leadership for Science Education
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Introduction: Leadership for Science and the Paradox of Plenty

K-12 American schools sit amidst an extraordinary variety of resources for science education. Contemporary science educators have access to a range of networks offering curricular innovation and professional development opportunities that can enrich their practice and spark their exploration of new scientific and technological fields. Science education and outreach receive a comparatively high degree of attention from federal funders: the National Science Foundation and the National Institute of Health require investigators to specify education and outreach activities, and the NSF commits over $800 million annually to science outreach, curriculum and professional development and program evaluation activities (American Association for the Advancement of Science, 2007). Governmental and non-governmental organizations have committed time and resources to the training and recruitment issues that are central to science education reform, resulting in an array of new pathways into science teaching, as well as new access to science education resources for under-represented groups of students. From the outside, it would seem inevitable that this wealth of science learning materials and professional development opportunities would make American science education a shining example of innovation and effective practice.

On closer examination, however, this "garden of plenty" looks very different. K-12 schools have long been regarded by reformers as places that hamper or distort the implementation of innovative science curricula. Researchers and policy-makers have identified numerous barriers to the widespread adoption of innovative practices, including the lack of alignment between local standards and innovative curriculum materials, the "mile wide and inch deep" nature of the standards that require teachers to focus on breadth rather than depth, and a chronic shortage of qualified teachers with the expertise to implement new approaches (National Science Foundation, 2006). These issues are compounded by pressures from outside the classroom. At the elementary school level, the testing mandates of the No Child Left Behind (NCLB) act have until very recently emphasized reading and mathematics at the expense of science. At the high school level, anxious parents expect schools to reinforce the traditional science course sequences as a reliable pathway to college admission. Science teachers, who may already struggle with inadequate subject-matter preparation, must cope with the combined demands of curriculum coverage, conservative community expectations and high-stakes testing. These pressures create a chilly climate for local innovation and experimentation.

Local school leaders play a central role in establishing the conditions for improvement in science teaching and learning (Leithwood et. al., 2004; Spillane, Halverson & Diamond, 2004). Although the push for instructional reform typically focuses on the classroom, teachers have little control over the out-of-school constraints on classroom practice. It falls to district and school leaders to manage these constraints and make space for science education reform. In this chapter, we take a distributed perspective on school leadership that focuses on the tasks rather than the roles or the organizational conditions of leadership (Spillane, 2006). From a distributed leadership perspective, the key question is to determine how a variety of K-12 formal or informal school leaders, such as principals, instructional coaches, lead teachers, department heads and district curriculum leaders, engage in the tasks that improve conditions for student learning (Spillane, Halverson & Diamond, 2004). While teachers focus on classroom issues, leaders can take a school-wide, "meta-classroom" perspective, promoting classroom reform by carrying out organization-level tasks such as acquiring and allocating resources, monitoring instruction, establishing partnerships within and across schools, and legitimizing preferred reform strategies.

We begin with the premise that without the involvement of school leadership the likelihood of meaningful, enduring change is small. Our goal is to explain why and how it is important to support school leaders in establishing the policy and practice conditions for science education reform. We do this by drawing a sharp contrast between the theory of action that has guided many science education reform efforts and theories of action grounded in local leadership practices. A theory of action is the network of assumptions, strategies, goals and resources that guide behavior (Argyris & Schön, 1974). In the first section of the chapter, we describe the characteristics of a theory of action that typically guides science education reform activities. This conventional theory of action seeks to influence local school conditions and improve student learning by establishing and implementing policies that focus on standards, curriculum materials, and professional development. This approach emphasizes content and pedagogy but often neglects the powerful influence of local conditions under which reform is expected to take root. In the second section of the chapter, we consider a different theory of action—one that guides science education reform from the perspective of local school leadership. We outline the community and policy constraints that shape the capacity for reform among local school leaders, and argue that successful leaders reshape organizations by treating these constraints as affordances for transforming instructional practice. In the final section, we offer suggestions for how reformers can connect their goals with local theories of action to promote science education reform at the organizational level. We hope that these suggestions will enable leaders and policy-makers to pursue reform agendas within the real-life constraints of school operation.

Components of the prevailing science education reform theory of action

Science education has been a national priority for over five decades. In this chapter we briefly review the history of national reform efforts and argue that the prevailing theory of action seeks to shape the context for innovation around schools, but treats schools themselves as "black boxes," either excluded from the reform agenda or, at best, dealt with indirectly. The prevailing theory of action has three central pillars: 1) establish *standards* that create a common set of expectations, lending order and coherence to what teachers teach; (2) create standards-based *curricular materials* developed by experts with deep subject-matter knowledge; (3) provide *professional development* opportunities focused on appropriate curriculum implementation. This theory of action holds that when these components are implemented simultaneously at the national, state and local levels, we can expect lasting changes in science teaching and learning.

Standards. Setting national-level content standards has been a central reform strategy for changing local practices. The famous report *A Nation at Risk* (National Commission on Excellence in Education, 1983) reserved some of its most trenchant criticism for science education, demanding that educators adopt "more rigorous and measurable standards and higher expectations for academic performance and student contact" (1983, p. 3).[1] At that time, decisions about the content of science instruction were made by university educators and textbook publishers, or through sheer institutional inertia and the force of tradition. Curricular materials were widely regarded as diffuse and outdated, emphasizing breadth over depth in a pattern that another prominent report condemned as "overstuffed and undernourished" (American Association for the Advancement of Science, 1991, p. xvi).

In the 1980s, reformers began to frame an agenda for improving science instruction that focused on nation-wide standards for high quality science learning. The benchmarks and standards published by the American Association for the Advancement of Science (AAAS, 1993) and the National Research Council (NRC, 1996) facilitated a profound shift in the conception, design and implementation of science education reform. These documents provided coherence where there had once been chaos. Embraced by many as a "mechanism for school improvement" (Porter, 1994) the AAAS and NRC standards were followed by reform documents such as the AAAS's Atlas of Science Literacy (2001), that connected standards to specific goals, learning outcomes, school improvement measures, and teacher development benchmarks to build a "standards-based" road-map for scientific literacy. Many state departments of education quickly adopted or adapted these national standards for their local and state-wide efforts to reform and standardize the science curriculum (Burry-Stock & Casebeer, 2003; Swanson & Stevenson, 2002). The commitment to standards continues to guide current reform efforts at both the state and national levels (Krajcik, McNeill & Reiser, 2008).

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[1] For an updated version of the rhetorical critique of science education, see the National Research Council's 2007 report, *Rising Above the Gathering Storm: Energizing And Employing America For A Brighter Future.*

Curriculum Materials. Developing and disseminating innovative curriculum materials has long been a favorite strategy by which researchers and policy makers have sought to influence classroom teaching and learning (Welch, 1979; DeBoer, 1991; Atkin & Black, 2003). New curricula, usually but not always in the form of textbooks, are a comfortingly familiar form of educational resource that can be easily adapted across a variety of classrooms and districts (Ball & Cohen, 1996; Schneider, Krajcik & Marx, 2000). The earliest federally funded curriculum projects from the 1960s provided not only textbooks but also laboratory materials and films (see Physical Science Studies Committee, 1960; Biological Sciences Curriculum Study, 1963). Early efforts to develop reform-based curriculum explicitly excluded teachers from the development process (c.f. Bruner, 1977; p. 19-20). More recent curriculum development efforts entail extensive classroom and subject-matter research, and aim to situate curricula within current standards and theories of learning (Singer, Marx, Krajcik & Chambers, 2000; Schneider & Krajcik, 2002; Krajcik & Reiser, 2004; D'Amico, 2005). The best of these research-driven curriculum products are developed and revised in response to school-based field testing, classroom observation and teacher feedback. Materials created in this manner range in scope from hour-long activities to multi-year programs, and vary in medium from textbooks to new technologies and laboratory activities.

Shortly after development, most new curricula are simply released "into the wild." It is rare for the developers to stay involved with the dissemination and further development of the materials, which then begin their own independent, market-driven existence. Rowan (2006) suggest that researchers and publishers who develop new curricula face internal pressures to move on to new projects, even if it would benefit teaching and learning for a school to maintain coherent curricula. With new materials constantly under development, it comes as little surprise that past generations of innovative curricula litter the field of science education reform. Even though their market share pales in comparison to that of the commercial publishers, the sheer volume of research-based curriculum material, particularly in secondary science, overwhelms the capacity of any particular school or teacher to keep up with recent developments. In addition, teachers and administrators have few tools for discerning the value of any given set of materials. Even *locating* earlier generations of resources can be a challenge. Commercially promising materials are sometimes acquired and sold by for-profit corporations, which further complicates the process through which curricula are presented to teachers and administrators. As a result, many organizations rely on gatekeeper internet resources, such as merlot.org, amster.com, and free.ed.gov that aggregate and index materials to provide easy access for practitioners. Although these websites serve an important consolidating function, they offer little guidance to teachers in choosing appropriate materials or implementing the materials they choose.

The commercial market poses further challenges for curriculum material dissemination. Standards-based reform is guided by the assumption that the producers of curriculum materials, in order to survive in a disordered market, will use standards to filter existing materials and to select innovative curricula to incorporate in new editions. Evaluations of middle- and high school textbooks conducted by the staff of Project 2061 (Kulm, Roseman & Treistman, 1999), however, turned up both startling omissions in content and a variety of extraneous material.[2] The disconnect between the hypothetical "focusing" function of standards-based reform and the reality of textbook content stems from the long-standing practice of layering new content on top of older material. Curriculum developers must also balance their interest in complying with national standards against pressures to deliver content familiar to current classroom teachers. In short, even without considering the attenuating effect of divergent implementation, the effect of curriculum-based reform is limited by the complex and chaotic marketplace for new materials.

Professional Development. In-service professional development is the final of three common components of the prevailing theory of action for science education reform.[3] Federally funded in-service professional development efforts may even pre-date curriculum development as a strategy to influence science teaching (Welch, 1979). As noted above, the inadequate subject-matter preparation of science teachers is frequently identified as a major barrier to the improvement of K-12 science education. Recent statistics reveal that only 72% percent of K-12 science teachers had a college major and certification in a science-related field, and 20% of high-school science teachers did not have appropriate subject-matter certification (NCES, 2008). Professional development projects, regardless of type, are intended to improve teachers' "science content knowledge, process skills, and attitudes toward teaching science" (Radford, 1998). This

[2] The Project 2061 textbook evaluation criteria are available at http://www.project2061.org/publications/textbook/hsbio/report/analysis.htm

[3] Pre-service teacher education is obviously important contributor to the preparation of science teachers. However, school-level leaders have little direct effect on teacher preparation programs. Reformers who wish to influence science education as a whole can address issues of teacher preparation (see, for example, NTSA, 2003; NRC, 2001), but we feel that those who seek to influence practice within the school need to focus on the resources and practices available to school-level leaders for improving teacher capacity.

is ideally done by providing teachers with "concrete tasks ... focused on subject-matter knowledge, connected to specific standards for student performance, and embedded in a systemic context" (Supovitz & Turner, 2000). Professional development may be provided as part of a curriculum development project; it may also be focused on a particular pedagogical approach or on the alignment of instruction or assessment with standards. For example, the National Research Council produced Professional Development Standards to accompany the National Science Education Standards. The NRC's *Professional Development Standard A* states that the "professional development for teachers of science requires learning essential science content through the perspectives and methods of inquiry. Professional development science learning experiences seek to involve teachers in actively investigating phenomena that can be studied scientifically, interpreting results, and making sense of findings" (NRC, 1996, p. 59).

Science professional development opportunities have resulted in a "menu" approach that results from the diversity of providers in the wider ecology of school improvement. Teachers and schools may choose among options that extend from biomedicine to nanotechnology and from physics to ecology; some topics reflect national standards while others do not, and the content of professional development programs can be delivered in broad strokes or very specifically. The NRC and the Smithsonian Institute, for example, offer four summer workshops to improve "teachers' understanding of science and pedagogy" in order for them to "become more able to engage young minds in the sciences" (NSRC, 2003, p, 11). At the other extreme, a 2008 NSF workshop on NSF Summer Institute in Applied Biotechnology & Bioinformatics at the University of California-Davis, promoted the integration of new high-technology skills and knowledge “into the traditional high school science classroom. Participants will learn biotechnology and bioinformatics skills and develop curriculum around various disciplines” (UC-Davis, n.d.). Discerning consumers of professional development can assemble a coherent learning trajectory from this menu of options. However, for many teachers, this diverse marketplace results in a fragmented and inconsistent professional development program. The prevailing theory of action, which relies on providing interested, motivated teachers with the option to acquire intensive experience with new science concepts and practices, fails to take into account the context of everyday practice.

Research on effective professional development for teachers finds that the amount of time teachers spend in professional development is strongly correlated with improved student achievement (Yoon, Duncan, Lee, Scarloss & Shapley, 2007). Effective professional development depends on the incorporation of teacher learning into daily instructional practice. As such, professional development projects are most effective when teachers are able to make explicit connections to their particular school contexts, ideally with the help of sustained, school-based follow up (Bredeson, 2002; Darling-Hammond, Wei, Andree, Richardson, & Orphanos, 2009). In short, effective professional development experiences need to both elicit opportunities for developing new ideas and provide a framework for integrating new ideas into the contexts in which teachers' actually work. As we will discuss in more detail below, the success or failure of these experiences implicitly relies on the support of school leaders.

Summary. Science education reforms have typically been developed in settings far from the local contexts where they will be implemented. Despite the best efforts of researchers to take "complex practices" and local conditions into account (Confrey, 2006), each new innovation will be transformed by local pressures and competing interests at the state, district, and school levels. The prevailing theory of action for science education reform is guided by a decontextualized view of teaching practice in which teaching can be shaped by standards, curriculum and professional development with little regard to the contexts in which practice takes place. Key leverage points for reform are identified at the level of policy, where standards are determined, in research universities, where science education resources and curricular materials are developed and in the classroom, where curriculum are chosen and enacted by teachers.

The school itself is absent from this theory of action. Summer institutes and workshops are typically offered at sponsoring university or research institutes (Westerlund et. al., 2002), removing teachers from the school setting for a period of time ranging from hours to days. Institutes and workshops effectively distance teachers from the day-to-day distractions of the classroom, and facilitate direct and unfiltered communication between teachers and teacher educators so that teachers can focus single-mindedly on exciting new material. However, professional development opportunities provided outside of schools can omit considerations of local context – in particular, how local conditions constrain the application of new pedagogies or curricula. Once they return to their schools, teachers must adapt new ideas to the existing culture and expectations of their schools and classrooms.

We argue that this theory of action is unable to engage schools in systemic change. Reform policies established and enacted outside the school are unlikely to be successful at the local level without a more careful consideration of the socio-cultural contexts of innovation. We suggest that school leaders, who create the spaces for innovation within highly routinized and change-averse institutions, are key to successful science education reform. In the next section, we examine the opportunities that leaders have created for innovative practice in the context of existing school systems, and use concrete examples to illustrate how reform-minded school leadership can help teachers and students make better use of the raw material of science education reform, including the standards, curriculum materials and professional training opportunities already in existence.

School Leadership and Reformed Science Instruction

As described above, science education reform is typically planned *outside* of schools for implementation *in* schools. The transition from good ideas about K-12 science teaching and learning to systemic improvements in K-12 science classrooms is the responsibility of school and district leaders. Teachers, by themselves, can and often do initiate innovative practices for teaching and learning. But without coordinated organizational support, teacher initiatives can be pushed to the margins of the school instructional program and rendered irrelevant to the overall instructional practices of the school. When teachers take on the tasks of transforming the organizational conditions of teaching and learning, they become *de facto* instructional leaders—but implementing systemic science reform requires both formal and informal leaders to take responsibility improving the school instructional system. Furthermore, the work of instructional leaders must necessarily address the local contexts that influence teaching and learning. From a school leadership perspective, whether science education reformers promote innovation through standards, curricula or professional development, they can only be successful if they engage the constraints that leaders face in designing a world for improving teaching and learning.

School leaders act as gateway custodians for the ideas and practices that drive systemic school improvement (Honig & Hatch, 2004). Leaders are responsible for bringing new faculty into schools and for measuring the adequacy of practice through the teacher evaluation process. Leaders acquire and allocate resources, including money, time and people, to support local instructional initiatives. Leaders typically authorize the selection (or the creation) of new school- and district-wide curricula and instructional programs. Within schools, leaders use their power to structure professional interaction among teachers. For example, leaders control the agendas for formal faculty interaction (e.g. meetings, team and departmental structures) and are responsible for building the master schedule that matches teachers, topics and students and provides for faculty planning time. Professional community, widely recognized as a key organizational prerequisite for substantive reform (Stoll & Louis, 2007; Bryk & Schneider, 2002), typically results from faculty interactions that take place in the meetings organized by school leaders.

School leaders are not always perceived by reformers to be positive contributors to innovation, however. In fact, the structures and processes they control are perhaps more frequently seen as obstacles to change. Leadership agendas can conflict with and neutralize reform efforts. Worse, the failure of leaders to create the capacity for improvement in teaching and learning can undermine teachers' efforts to pursue meaningful reforms. The failure to establish conditions for improvement can be rooted in a lack of leadership will and skill. However, the difficulty in improving the conditions of practice is also a reflection of the highly constrained design spaces within which leaders work. School leaders work in complex *systems of practice* shaped by structures and priorities that are the result of historical decisions about the organization of teaching and learning (Halverson, 2003). Many features of a school's system of practice are beyond the scope of local school leaders' capacity to change. For example, practices concerning age grading, union contracts and special education provide significant constraints on the range of innovation. Faculty members also come to schools with strong beliefs about how teaching should be organized and deeply formative prior experiences that guide their interaction with students. The increasing use of standardized assessments and curricula at both national and state levels constrains instruction not only in the classroom but also across grades and among schools. As these new standardized structures are incorporated into the daily work of schools, they form a resilient system of practice that is remarkably resistant to change.

District and school leaders create the space for instructional change by addressing or co-opting the external pressures that bear most heavily on their school. Many leaders become so focused on responding to accountability pressures that they exercise their power to create the impression of compliance with policy demands while avoiding significant changes to instructional program (Meyer & Rowan, 1983). Other leaders seek to orchestrate substantial instructional changes in some subject areas while leaving other areas unexamined (CEP, 2007). In the language of decision-making, these leaders engage in "satisficing" behaviors (Simon, 1983) that help schools meet accountability requirements but also address local pressures to maintain existing practices. As local leaders gauge competing pressures to improve different areas of the instructional program, science reform seldom emerges as the top priority (even as international comparisons push science as a national priority).

In the following pages, we engage in a two-part discussion that first draws out how local contexts blunt reform, then identifies the leverage points can be used to reinvigorate reform efforts at the local level. We discuss the different ways in which the science education reform agenda is filtered through the policy pressures that operate at two levels of the K-12 educational system: elementary schools and high schools. Our analysis will demonstrate the how differing institutional contexts guide (and qualify) leadership efforts in distinctive ways. At the elementary level, we describe how the science reform agenda has been co-opted by the high-stakes accountability pressure to improve reading and writing. At the secondary level, we describe how leaders in high-poverty districts must make do with a shortage of resources, while leaders in resource-rich districts face pressure from empowered parents to preserve existing practices that they interpret as critical to college admissions. At first glance it may seem that these pressures simply stifle science education reform. However, in our subsequent discussion, we point to leverage points that science reformers can exploit within the current contexts to further the goals of science education reform.

The Context of Elementary School Leadership.

Much of the attention for science reform has been justly targeted at early elementary school programs. However, science reformers have become increasingly frustrated by school-level resistance to innovative practices. This resistance is the direct result of high-stakes accountability policies. Elementary school leaders and teachers have reshaped mathematics and language arts instruction in response to the high-stakes accountability demands of the No Child Left Behind Act (2001). Even though high-stakes tests are required in science, most schools have chosen to focus on raising achievement in math and language arts (Marx & Harris, 2006). Schools have increased the allotments of time for mathematics and literacy instruction and reduced the time and resources available for science. A Center on Education Policy (2007) report found that, from 2001-2006, elementary school instructional time in English and language arts increased by 47%, and math instructional time increased by 37%. About 1/3 of this increase in instructional time came at the expense of science instruction (CEP, 2007).

The increased attention to literacy instruction, in particular, is transforming the quality of science instruction. When elementary schools do make a commitment to science education reform, it often takes the form of content-based literacy instruction. Lee and Luykx (2005), for example, felt the need to persuade school leaders and teachers of their science intervention's value by describing how it could improve the students' reading and literacy skills. In this context, science instruction can be stripped of its focus on experimentation and inquiry. The design of state science tests typically emphasizes reading comprehension and inference skills over specific subject matter knowledge, asking students to answer multiple-choice questions based on their ability to make inferences from short textual passages. While critics such as Yager (2005) argue that the reduction of science to literacy misses the main point of teaching science, the format of existing state tests suggest to many leaders that elementary science can be adequately addressed as a form of reading comprehension.

Examples of Elementary School Reform: Formative Assessment and Professional Communities. Although the pressures of high stakes accountability policies in mathematics and language arts divert attention from science education reform, some elementary school leaders have responded in ways that leave the door open for substantive improvement in science as well as literacy and mathematics education. Two important leadership strategies that characterize local theories of action are investment in formative assessment practices and the creation of professional communities to share local expertise. Both strategies contain lessons for reformers seeking to improve science teaching in a high-stakes accountability environment.

It is difficult for schools to make use of existing standards-based state assessments for formative assessment of student learning.[4] Information from state tests is neither timely nor aligned with local instructional practices. The results of state tests take too long to arrive for teachers to use information to adjust their instructional programs. And, even in the best of circumstances, where the state tests are aligned to the state content standards, specific items may be only loosely related to the school's instructional program. These limitations have led school and district leaders to either purchase benchmark assessment systems from external vendors or develop local formative assessment practices to guide teaching toward tested outcomes (Mandinach & Honey, 2008). The effectiveness of local formative assessment practices is limited without opportunities for teachers to share testing results in the context of existing lessons, quizzes and homework, and to discuss with their colleagues the implementation of new

[4] This perspective on formative assessment is substantially different from the version advanced in the classic Black & Wiliam (1998) discussion. Early work on formative assessment emphasized providing pupils with appropriate feedback to guide the learning process. Contemporary discussions of formative feedback position teachers, instead of students, as the crucial learners. Benchmark assessment systems, for example, provide teachers with information on student learning as formative feedback on *teaching* practices. (For more detail on this shift in the use of formative assessment, see Halverson, Prichett and Watson, 2007.)

approaches (Newmann & Wehlage, 1993). This process of enriching instructional practices with formative assessments, when and where it occurs, gives teachers a path toward collective ownership of the school instructional program.

Assessments produce information about learning, but schools need professionals who are capable of acting on information in order to make a difference for students. In response to that need, many elementary schools have improved student outcomes, particularly in language arts, by cultivating internal instructional expertise in robust professional communities. These communities combine curricular initiatives, coaching, and team teaching to leverage insights sparked by commercial or homegrown formative assessments (Halverson, 2009; Blanc, Christman, Hugh, Mitchell & Travers, 2009). While some of the research on coaching initiatives suggests that resources dedicated to support coaches are misallocated or co-opted by pre-existing instructional priorities (e.g. Mangin & Stoelinga, 2007), other studies conclude that coaching provides a promising strategy to improve professional practice in schools (Showers & Joyce, 1996).

The continuous interaction around teaching, coaching and formative assessments can create what Bereiter and Scardamalia (1987, p. 106) call *second-order environments* that foster progressive problem-solving activities and push participants to continuously examine and revise their own expertise and generate new, innovative solutions. Such learning communities rely on teachers and other professionals who are trained in new practices to enhance existing school expertise and catalyze new opportunities for interested colleagues to acquire useful knowledge and skills. The best professional communities allow teachers to work with coaches and support staff to try out new practices in classrooms, and to use formative assessment data to measure the degree to which those new practices improve student learning. Second-order environments provide a chance for teachers to get both learn about new ideas in conversation with colleagues and to sharpen practices through collaborative experimentation. Thus, professional communities provide a path for leaders to both distribute existing expertise and catalyze the development of new instructional expertise.

We do not suggest that it would be easy to simply shift the focus of formative assessments and professional expertise development from math and literacy to science. Assessment becomes formative when it sparks the kinds of communication and reflection that successfully transform practice. Simply providing benchmark science testing data to school communities who do not have sufficient expertise may simply result in more data overload. Elementary schools often start with fewer subject matter experts, which puts a premium on the ability of the school to generate the internal capacity for teachers to share information on teaching and learning. However, as school leaders increasingly move toward a theory of action focused on professional community and grounded in formative measures of student learning, it is possible to see how new approaches to teaching and learning might emerge in science as well as mathematics and the language arts. Science educators can learn from the experience of school leaders in structuring professional communities to amplify expertise in these fields. This would mean developing benchmark science assessments that catalyze deep insights for students and teachers, and fostering in-school professional community that supports teachers as they try out new practices and discuss the results of their innovation. If professional development opportunities allow teachers to engage with innovative content as learners, and link that content with benchmark assessment data, they could help teachers understand patterns in student learning. Furthermore, situating opportunities to learn science in the context of pre-existing efforts to improve literacy instruction could help teachers transfer their professional learning strategies to new domains. By aligning their efforts with the theory of action that guides literacy and mathematics education, science educators may be able to make accountability demands work in their favor.

The Context of Secondary School Leadership.

The challenges of improving science instruction are different and perhaps more complex in high schools. While many elementary schools have been able to change internal practices to meet the demands of NCLB accountability policies in mathematics and language arts, secondary schools continue to struggle to achieve basic goals such as preventing student dropout and providing adequate preparation for college-bound students. It has been remarkably difficult to reform instructional practices in high schools, even in high-achieving schools that would seem to possess the resources to support reform. As we will argue in the next section, the culture of professional autonomy and public pressure for narrow definitions of success pose obstacles to reform in all secondary schools. The resistance to change in both high- and low-resource contexts points to a crucial role that school leaders can play in identifying the key instructional areas for experimentation and innovation. This section will outline the contexts within which secondary school leaders work by tracing how the traditions of professional practice and organization, together with community pressures, reinforce existing models of science instruction. We then describe *Project Lead the Way*, an example of how innovations might be designed to take advantage of the contexts in which secondary school leaders engage in science reform.

Traditions of Professional Practice and Organization. The first obstacle to system-wide reform in secondary science education stems from existing traditions of professionalism. High school teachers have strong traditions of autonomy and define their professional roles according to their personal beliefs about what students can and should learn (McLaughlin & Talbert, 2001). The structure of professional interaction in secondary schools reinforces these traditions through academic departmental structures that often act as professional confederations rather than learning organizations (Siskin, 1995). This is not to say that high school teachers are reluctant to embrace new ideas and practices: many of the most exciting high school innovations are developed by teachers who use their autonomy to fundamentally alter instructional traditions. Clifford (2009) described how high school science teachers in two schools used strong collegial relationships and external university and professional organization networks to create the conditions that enabled them to successfully modify their teaching. Still, their reform efforts depended on teachers and schools willing to take on leadership tasks. Without such risk-taking leadership, school administrators and academic departments can simply reinforce teacher autonomy, making it difficult for secondary school leaders to support or instigate cross-school instructional innovation.

How Student and Parent Expectations Contribute to Curricular Rigidity. The second obstacle to school-wide reform in secondary science education derives from the interplay between student aspirations, parent demands and college admissions standards. This interplay creates pressures on high school leaders to assign the school's most qualified teachers to the highest achieving students in a traditional science curriculum sequence. Secondary school student populations are typically divided into two kinds of students: those for whom high school is a viable path to higher education, and those for whom high school is the last stop in the educational process (Sedlak, Wheeler, Pullin & Cusick, 1986, p. 48). Students in the first group, those for whom high school is a path to college, expect to take a specific sequence of classes (typically involving biology, chemistry and physics) that articulate neatly with the admissions expectations of selective colleges. Although the traditional sequence has been supplemented by the addition of Advanced Placement courses, it has remained substantively unchanged for decades.

States reinforce the traditional course sequence by increasing science course requirements for graduation. By 2006, over 40% of US states, encouraged by reform efforts such as the American Diploma Project, raised graduation requirements in "higher-level" science courses such as chemistry, physics, biology, physical or earth sciences, to 4 credits. Such traditional coursework fits the expectations and admissions requirements of most state and private university systems. The University of California system, for example, advises students to take biology, chemistry and physics; the state of Washington requires incoming high school students to take two years of laboratory science, including one year of biology, chemistry or physics to be considered for admission into state university.[5] Since college admissions programs review transcripts rather than course content, high schools feel pressure to maintain existing course titles, since alternative titles can give the appearance of a less rigorous curriculum. Finally, parents' perceptions of college admission requirements lead them to demand the kinds of programs that lead to successful college admission (Henderson & Berla, 1997). The press for a "legitimate"

[5] California data can be found http://www.admissions.ucla.edu/Prospect/adm_fr/fracadrq.htm; Washington at http://www.hecb.wa.gov/research/issues/documents/MCASOverviewstudents.pdf

and high quality science course sequence brings together faculty members with strong science credentials to teach in the core academic program (Murphy, Beck, Crawford, Hodges & McGaughy, 2001).

The college-preparatory academic program contributes to a *de facto* tracking system that splits students into science haves and have-nots (Lucas & Berends, 2002; Gamoran & Weinstein, 1998). Because a high percentage of students in the college-preparatory track already meet state minimum competency standards, the high-resource college-preparatory track would seem a natural home for science innovation. Unfortunately, the conservative atmosphere that surrounds the core academic program results in a narrowly defined focus on achievement rather than curriculum reform or innovative instruction. New courses organized around content areas such as nanotechnology, systems biology, information sciences or engineering can have difficulty gaining acceptance in the college-preparatory track in part because there is no perceived room in the traditional course sequence for college-bound students, and in part because the existing courses have not prepared students to engage in the core concepts of emerging areas of inquiry.

When the most experienced teachers are matched with college-bound students in the traditional core sequence of science course, the most innovative reform-based science programs may need to be implemented outside this sequence. This presents a challenge for teachers outside the college-preparatory track, who often have weaker science backgrounds and professional networks. Also, though offering reform-based science education courses outside the college-preparatory curriculum may increase the school's capacity to address the needs of traditionally underserved students, it does not obviate the need for reform in college-preparatory science. Strengthening science education in high schools, both within the college preparatory track and outside of it, requires leaders to create space for innovation.

An Example of Secondary School Innovation: Project Lead the Way. In the elementary school section (above) we described an emerging theory-of-action focused on the development of assessment-driven professional communities, as a way to help reformers situate science reforms in existing school contexts. In the secondary schools section we describe a specific intervention to highlight how reformers have situated innovative programs in existing school contexts.[6] To illustrate how innovative program design can support local efforts to operate *within* these constraints, we briefly consider one of the more compelling contemporary examples of comprehensive reform: *Project Lead the Way* (PLTW). This reform has strong roots in career and technical education, outside of the traditional college track, and emphasizes connections across subject-based departments. We do not argue that PLTW is the first or the only program to succeed in secondary schools; instead, we use PLTW to illustrate how a program can be designed to work within the constraints of existing schools and to reveal how secondary school leaders and teachers can create spaces for reformed practice.

First implemented in 1997, PLTW is a nationally recognized high school pre-engineering program that integrates a series of traditional science and math classes with

[6] Middle schools and junior high schools present yet another set of design challenges for science reform. In many ways, middle and junior high reform rests part way between the issues of elementary and high school contexts – middle school programs face accountability pressures similar to elementary schools, while many middle school faculties share the departmental organization of high schools. The interdisciplinary organization of many middle-level instructional programs, however, provides a unique affordance for the design of science interventions. For a discussion of the developments and challenges of science reform in middle and Junior high schools, see Lee, Songer, & Lee (2006); Ruby (2006); Hewson, Kahle, Scantlebury, & Davies (2001) and Kesidou, S. & Roseman, J. E. (2001).

another series of project-based learning courses that require students to apply mathematic, scientific and technical knowledge to address engineering problems. PLTW includes a two-week professional development program for teachers and a standardized exit exam. Bottoms & Uhn (2007) found that PLTW students scored significantly higher than their peers on a NAEP-referenced test of math and science, and that PLTW students were more likely to complete four years of math than their peers. Phelps, Camburn and Durham (2009) found that PLTW students reported significantly higher levels of intellectual openness than their peers, as indicated by their willingness to discuss open-ended questions and their desire to learn. Over 3000 schools in 50 states use the program.

Each PLTW school signs a contract to abide by the conditions for participation. The PLTW contract reveals critical features of a theory of action about how leaders in secondary school instructional programs can support innovation (Project Lead the Way, 2007). PLTW requires participating schools to engage in a partnership with other districts, colleges and universities and the private sector. Although the program uses a traditional summer workshop training approach to prepare the participating teachers, it also includes in-service training intended to link teachers with external networks of ideas and professionals focused on PLTW implementation. Participation in broad professional networks external to the school has been identified as an important aspect of successful school reform (Huberman, 1995; Lieberman 2000). The structure of PLTW requires schools to serve as "model" programs, available for observation and inspection by other participating schools. Inter-school visits replicate some aspects of the professional communities that elementary school leaders use to promote change in literacy and math instruction.

PLTW also requires schools to commit significant resources to implementing the program. First, a school must obtain district-level approval for the program. The school must also implement four new courses in engineering to ensure that the program is integrated into the school instructional sequence. Students participating in PLTW must enroll in at least 2 classes in the school math program. Because PLTW is seen as an alternative to the traditional science sequence, college-prep students may opt out of PLTW enrollment. However, because PLTW provides a viable science course sequence and a link with the existing school math program, new students motivated by the engineering perspective on science may begin to break down the *de facto* wall between academic and non-academic tracks. By creating extended professional networks and integrating an engineering perspective into the existing academic program, the PLTW program demonstrates how reforms can produce sweeping changes in science education by tapping into the existing resources of a school community. School leaders who are already committed to the development of professional community and program integration can build on the foundation of new programs such as PLTW rather than approaching innovation as a distraction from existing priorities.

Affordances for Change

In this final section, we focus on the role of school leaders in encouraging and sustaining innovative practices that improve student achievement. Our discussion thus far has described constraints that limit the range of action for instructional leadership as well as promising theories-of-action that have sparked innovative reform in the context of these constraints. Here we generalize four leverage points for reformers to consider in supporting science reform from a school leadership perspective: connecting teachers with each other, connecting teachers with resources, protecting the early stage of innovation, and building the subject-matter capacity of teachers. For each leverage point, we suggest how reformers *outside* of schools can address the existing constraints of school reform in ways that can support the work of school leaders in enacting change.

Connect Teachers with Each Other. The development of professional communities among teachers, as described in the elementary school section (above) should be a central feature of a school-based theory of action for science education reform. Professional communities have several benefits in the context of highly constrained, tradition-bound systems like schools (Louis, Kruse & Bryk, 1995; Halverson, 2003; Bryk & Schneider, 2002). First, teacher collaboration promises to increase the depth and rigor of reform by creating a shared focus on persistent classroom dilemmas. Research suggests that collaboration enables teachers to test hypotheses about practice and address instructional problems at a deeper level (Krajcik, Blumenfeld, Marx & Soloway, 1994; Thompson & Zeuli, 1999; Loucks-Horsley & Matsumoto, 1999). Second, collaboration increases the efficiency of reform by enabling teachers to benefit from the expertise and experience of their peers. Teachers who receive help from colleagues who are already implementing new projects report they are significantly more likely to change their own practices (Penuel, Frank and Krause, 2006; van Driel, Beijaard and Verloop, 2001). When those more experienced teachers act as "peer coaches" or "teacher leaders," the gains may be substantial (Ruby, 2006). Developing and using teacher leaders requires time (i.e., release from normal classroom responsibilities) and training to achieve results. On the other hand, school leaders may have a greater impact by freeing up the time of a qualified and competent teacher leader than they can through direct, ground-level involvement. Third, collaboration among teachers increases the durability of reform both by enabling teachers to share the burden of innovation and by creating social reinforcement structures for positive change. Case study research suggests that reforms are easier to sustain and less vulnerable to external pressures when implemented by groups of teachers (Lee, Songer and Lee, 2006). Finally, a strong sense of community among teachers is linked to greater student achievement (Ross, Hogaboam-Gray and Gray, 2004).

How can reformers help school-level leaders create professional communities? A first step here might be to encourage school leaders to participate in the professional development activities provided to science teachers.[7] This would both improve leaders' own understanding of innovation and signal their support for ambitious changes in classroom practice (Gerard, Bowyer & Linn, 2008). School-level leaders are typically less knowledgeable about science content and science pedagogy than the teachers they supervise, and, as such, are not well positioned to discern the value of a given science education reform or its relation to other instructional initiatives.[8] On the other hand, leaders are ideally positioned to identify teachers who can take a stronger role in leadership practices. While school-level leaders might resist becoming intimately involved with on-going reform efforts for the same reasons that senior managers avoid becoming deeply involved in any particular product or initiative, leaders with an idea about the direction and value of a reform initiative could help cultivate the organizational

[7] At first, leader involvement might have a chilling effect on teacher's willingness to question their knowledge and practices. However, over time, the participation of formal leaders might help to build a professional community around knowledge instead of rank.
[8] According to 2007 data from the Wisconsin Department of Public Instruction, only 5.5% of certified administrators in Wisconsin, for example, have degrees or credentials in any of the sciences.

conditions for effective adoption.

Reformers should promote the use of distributed leadership strategies, in which leaders delegate some responsibility for school-wide instructional reform to teachers. Distributing responsibilities to specialists, coaches and department chairs empowers teachers to establish or change instructional program priorities (Clifford, 2009; Spillane, 2006). School leaders can release teacher leaders from some of their teaching responsibilities in exchange for reform-specific mentorship and management duties. The growth of community depends on collective ownership of reform or professional development projects. Leaders should find ways to involve all teachers in meaningful, reform-related work—even (especially!) those who are initially reluctant to participate. Finally, reformers should connect school leaders with professional networks outside of their own schools. Unlike school leaders, who are experts in their local context, outside reformers are ideally positioned to build bridges to professional communities beyond the school walls, both in other schools and in universities and parallel research communities. Communities in which either subject matter or reform expertise is sparse may need to rely on distributed, virtual expertise networks such as on-line discussion groups or virtual university programs. By encouraging visits and collaboration across institutional lines, reformers can help teachers gain a new perspective on their existing instructional practices and develop innovative practices that suit their particular contexts.

Connecting teachers with resources. Another central feature of a school leadership-based theory of action for science education reform is linking teachers with curricular and community resources. This strategy connects with two aspects of the existing reform-based theory-of-action: curriculum and material development. Research suggests that school leaders can play a critical role in science education reform by connecting teachers with resources (Spillane, Diamond, Walker, Halverson & Jita, 2001). Although some resources will be out of reach for financially struggling districts, financial hardship is not an insurmountable barrier to reform. Leaders in resource-poor schools show how the astute use of social capital and access to local, low-cost resources can contribute to successful innovation:

> ...in investigating the identification and activation of resources for leading science instruction it is imperative to look beyond the particular school to the multiple contexts in which that school is nested. [A]n interagency perspective, as distinct from an exclusive focus on the individual school, is important…to understand the resources for change. [I]t was essential to look beyond the school to the various agencies with which…staff networked in order to forge change in science education. (ibid., p. 937)

University research projects have always created opportunities for schools to access cutting edge professional development or curriculum projects. Savvy leaders in high-poverty schools can develop research-based partnerships that provide resources for science education reform. The richness of the science education resource pool truly becomes an asset for schools without ready access to community-based collaborators. Although some well-known curricular innovations are only available for purchase, many other innovative packages can be obtained at low- or no-cost. For example, schools wishing to incorporate innovative curriculum materials could use the well-established (and essentially free) Bottle Biology program as a starting place (cf. Krajcik, et al., 1996). Reformers at the district level can create legitimate opportunities for schools to engage in new practices by collecting and distributing information on these resources and on the professional networks that use them.

Reformers could also focus on helping schools access a particular kind of resource: assessment tools and practices. One of the lessons that teachers, leaders and reformers have drawn from the NLCB era is that internal instructional practices can be usefully restructured to help meet testing goals. Meeting the demands of high-stakes accountability has created a new market for assessment products (Burch, 2009). In all likelihood, testing will continue to drive instructional practice and reformers will continue to develop and distribute high-quality assessments to influence teaching and learning. The implementation of formative assessment tools, in particular, can strengthen existing professional communities as teachers work together to make sense of assessments in terms of their daily practices (Prichett, 2007).

Some of the curricular innovations referenced in the first section of this chapter, such as The Full Option Science System (FOSS), contain examples of how assessments can be integrated into curriculum materials.[9] Many innovative science materials are developed hand-in-hand with new learning technologies—often the same technologies that have been used to pioneer performance assessment systems (Mislevy & Knowles, 2002) or video-game development (Gee, 2003). The Calipers project (Quellmalz, et. al. 2007), for example, demonstrated how technological simulations can allow teachers to engage in formative assessment of student learning; the Compass project (Puntambekar, 2006) showed how new technologies can be used to assess student collaboration. While many of these interventions suffer from the limitations of research-based innovation described above, new markets have emerged in recent years to satisfy increasing school-based demand for formative assessment tools (Burch, 2009). Reform-oriented researchers can take advantage of new market opportunities by developing next-generation

[9] http://www.fossweb.com/

assessment tools that support rather than compete with instructional innovation (see, for example, Buxner, Harris & Johnson, 2008).

Protect Innovations During the Early Stages. A third feature of a leadership-based theory of action for science education reform is an understanding of the developmental stages of innovation. Our current thinking about instructional reform is dominated by fidelity models that emphasize the consistency with which an innovation is employed or implemented, and rush to judgment about an innovation's success based on early student outcomes. This binary, and often premature, judgment about success or failure can overlook the developmental effects that reform has on a school's instructional capacity. Larry Cuban's 1998 essay about success and failure in comprehensive school reform is particularly instructive. Drawing on several examples from the history of school reform, Cuban describes how premature judgments of success or failure can cripple a reform project. When a reform is judged a failure in its early stages, public approbation and pressure to abandon the project make any further progress difficult. On the other hand, reforms that are seen as early successes may also suffer when school and community attention shifts to "unsolved" problems. To further complicate matters, "success" means different things to practitioners than it does to reformers and concerned parties outside the school. According to Cuban, teachers emphasize the adaptability of a reform to local circumstance over fidelity to the original reform vision, and prefer a long-lived reform to an intensely but temporarily popular one. School leaders, under pressure from community members and policy-makers, may have exactly the opposite preferences. These differing ideas of success can lead to conflict.

Taylor (2001) reinforces Cuban's analysis, drawing attention to the particular vulnerability of reforms in their early stages. After listing a number of factors that combine to make reform more difficult, Taylor admonishes reformers within and outside of the school to support innovation and experimentation through sustained professional development and community-building. He also notes that it is critical to buffer reforms from inevitable fluctuations in external support. Protecting particular reform projects means committing to a consistent reform focus, including necessary professional development resources, for a period of years rather than months. It means protecting teachers engaged in the early stages of reform from community pressures and suspending judgment on innovative projects until they have time to reach their potential. Reformers who seek to introduce new ideas from outside of the school should urge school leaders to recognize the fragility of early innovation and relieve participating teachers of the need to show immediate results. Within the school, it is probably a good idea to set benchmarks and timelines at the beginning of the reform process, so that school leadership and teachers share a common set of expectations about the progress of reform.

Individual reforms can contribute to or detract from on-going efforts to improve school instructional capacity. Maintaining the coherence of a school's instructional is an important aspect of high-quality school leadership (Newmann, et. al, 2001). Reforms with differing instructional outcomes, agendas and resources compete for scarce professional development bandwidth in schools and distract teachers and leaders from a focus on school wide goals. To avoid this problem, leaders must select reforms that reinforce and extend prior efforts to build instructional capacity. As we outlined above in the examples of literacy-based professional community and *Project Lead the Way*, grounding new reforms in existing capabilities can create a fertile environment for instructional change. A school-wide focus on instructional reform can run counter to the tradition of teacher-directed innovation, however. Savvy leaders recognize the necessary balance between bottom-up and top-down reforms, and can reconcile this apparent opposition by promoting the adoption of innovations that stretch existing capacity in interesting and important ways.

Build the Subject-Specific Competence of Teaching Staff. We have already recommended that reformers help school-level leaders focus on building teacher collaboration, connecting teachers with key resources and protecting new reforms. To enhance the effectiveness of each of these measures, we recommend that school-level leaders act aggressively to build the science knowledge of their teaching staff, both by hiring new teachers with strong science preparation and by pursuing science-oriented professional development opportunities for veteran teachers. Researchers have repeatedly demonstrated a strong connection between teachers' content preparation and their teaching practice, as well as a positive link between content preparation and student achievement (Monk, 1994; Supovitz & Turner, 2000). However, we would not advocate simply importing experienced scientists directly into classrooms. Becoming a teacher involves more than simply applying content expertise – it means developing sophisticated models of pedagogical content knowledge (Shulman, 1986) through experience in of the concrete practices of teaching and learning. Furthermore, given the dominance of the traditional pedagogy in pre-professional preparation for scientists, many innovative approaches to science education will be at odds with the training of practicing scientists. We suggest that leaders should consider the science teaching capacity of staff *collectively*, and deliberately bring together clusters of teachers who are able to support each other in new instructional efforts.

There are at least three ways in which school-level leaders can work to improve teachers' science content knowledge and support innovative science instruction. First, the success of professional communities rests on the staff's ability to share and develop their expertise. The scientific expertise of particular teachers is a critical resource for collegial interaction, and the development of new science-related knowledge and skills can provide a powerful catalyst for professional learning across the entire teaching staff. Second, experience with scientific inquiry in authentic contexts may lend teachers credibility in discussions about the relevance and advantages of a science education reform project. Although school leaders may work to protect them from external pressures, teachers may encounter challenges from parents and community members who stress more traditional science course sequences. Teachers with experience in scientific research may have greater legitimacy in community-wide discussions about the advantages of innovative science instruction. Finally, a community of teachers with strong *collective* science preparation will probably be most capable of choosing and enacting high-quality content-centered reforms (Radford, 1998). Teachers' collective experience with science should enable them to judge the quality of curriculum materials and avoid those that favor visual or technological flash but lack scientific or pedagogical substance. A high level of comfort and confidence with the scientific content will also enable teachers to focus more on pedagogical innovation and on adapting the reform materials to their school and classroom context.

It is crucial to consider the collective competence of the teaching staff in addition to the individual strengths of its members. In a highly collaborative context, it may actually be beneficial for teachers to have widely diverse backgrounds and strengths (Shulman & Shulman, 2004). Although we caution against overzealous use of alternative certification pathways for reasons outlined above, we do support the judicious use of such strategies to recruit teachers with strong science preparation—in the context of a strong and supportive teacher community. Although these teachers may lack some important pedagogical skills and classroom-specific preparation, their scientific knowledge and experience will be an asset to their communities even as they themselves benefit from the pedagogical expertise of more traditionally prepared teachers.

Whether or not new hiring is possible, it is and will continue to be important to identify science-focused professional development opportunities. Ongoing professional development is important because the positive effects of subject matter preparation appear to diminish over time, as teachers forget their more advanced science training or that training becomes obsolete (Monk, 1994). Because contemporary science reforms often emphasize inquiry skills and the social and epistemological nature of scientific work, we suggest that experience in scientific research is a particularly important piece of teachers' subject preparation, and a particularly exciting strategy for teacher professional development.

Conclusion

This chapter contrasted the theory of action that often guides science education reform with a school leadership-based theory of action that accounts for as the constraints of local values and practices. We do not oppose reform that focuses on standards, curriculum resources or out-of-school professional development. These are and will continue to be important pieces of the puzzle. Content standards will continue to provide the learning goals toward which educators can aim their efforts, and have the potential to organize a coherent system of curriculum, instruction, and assessment. But without paying attention to the world of school leaders—the local conditions and the organizational structures that make up a school and shape its interactions with the local community—reform policies are less likely to be successful. There are many innovative and interesting curriculum-centered resources and professional learning opportunities for teachers. The challenges are choosing the right resources for the local context, creating access to internal (professional communities) and external (university and professional organization) networks that enable innovative practices to take root and bloom, and creating the space to keep new practices alive for a long enough time to make a difference.

Blumenfeld, Fishman, Krajcik, Marx and Soloway (2000) argued that reforms are most likely to succeed when they "fit with existing school capabilities, policy and management structures, and organizational culture." Successful reformers need to work with and through school leaders simply because school leaders are best positioned to evaluate the "fit" between a reform project and the local context, and can therefore play an important role in directing teachers toward reforms that are well suited to the overall circumstances of the school.

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