School Leadership for Science Education

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1. Introduction: The Paradox of Plenty

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.

This "garden of plenty" looks very different when viewed from the classroom perspective. Schools have long been regarded as places that can hamper 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 coverage rather than depth, and a chronic shortage of qualified teachers without the expertise to implement the new materials. (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 act have until very recently emphasized reading and mathematics at the expense of science. At the high school level, anxious parents perceive science programs as a pathway to college, and expect schools to reinforce the traditional sequence and content of science courses. Science teachers, including teachers already struggling due to inadequate preparation, must cope with the combined stress 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. Although the push for instructional reform typically focuses on the classroom, teachers and staff 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. School leaders have a "meta-classroom" perspective, promoting classroom reform indirectly by acquiring and allocating resources, monitoring instruction, establishing partnerships within and across schools, and legitimizing preferred reform strategies. Without the involvement of school leadership, the likelihood of meaningful, enduring change is small.

This chapter explains why and how it is important to support school leaders in establishing the policy and practice conditions for science education reform. Our strategy is to contrast the theory of action of science education reform with local school leader theories of action. A theory of action refers to the network of assumptions, strategies, goals and resources that guide behavior (Argyris & Schön, 1974). In the first section, we describe the characteristics of a theory of action that typically guides science education reform activities. This conventional theory of action seeks to establish and implement policies around the use of standards, curriculum materials, and professional development that influence local school conditions in hopes of improving student learning. This approach emphasizes content and pedagogy but typically neglects the powerful influence of local conditions under which reform is expected to take root. In the second section, we consider a theory of action that guides science education reform from the perspective of local school leadership. We outline the community and policy constraints that limit local school leader capacity for reform, 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 link with local theories of action to promote science education reform at the organizational level—suggestions that we hope will enable leaders and policy-makers to pursue reform agendas within the real-life constraints of school operation.

2. Components of the Science 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, focusing on the theory of action underlying three central reform strategies: the creation of standards documents, the development of curricular materials and the provision of professional development opportunities. We 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.

Standards

Setting national-level content standards has been a central reform strategy for changing local practices. The famous *Nation at Risk* report (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). At that time, decisions about the content of science instruction were being made by university educators, textbook publishers, or through sheer institutional inertia and tradition. Curricular materials were widely regarded as diffuse and outdated, emphasizing breadth over depth in a pattern that one 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 setting 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 common standards continues to guide current reform efforts at both the state and national levels (Krajcik, McNeill & Reiser, 2008).

Curriculum Materials

Developing and disseminating innovative curriculum materials is a perennial favorite method for researchers and policy makers seeking 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). Many new curricula are the products of extensive research, and are carefully aligned with current standards and theories of learning (Singer, Marx, Krajcik & Chambers, 2000; Schneider & Krajcik, 2002). Although active classroom teachers may have little direct input into the initial goals and strategy of the curriculum development project, 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. For example, 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). More recent attempts have continued to produce abundant curricular materials (Krajcik & Reiser, 2004).

Shortly after development, most new curricula are simply are 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. 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.[1] Even *locating* earlier generations of resources can prove a challenge. Commercially promising materials are sometimes acquired and sold by for-profit corporations, which further complicates the process by 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 provides 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. Recent 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. The disconnect between the "focusing" function of standards-based reform and the reality of science textbook content stems from the long-standing practice of layering new content onto previously existing material. Curriculum developers must balance their interest in complying with national standards compliance 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.

Out-of-School Professional Development

Out-of-school professional development is the final of three common components of the prevailing science education reform community theory of action. Federally funded 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. Nearly a quarter of science teachers lack preparation in their respective content areas, and many teach under emergency certification programs (Loucks-Horsley & Matsumoto, 1999). Professional development projects, regardless of type, are intended to improve teachers' "science content knowledge, process skills, and attitudes toward teaching science" (Radford, 1998). This is typically 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 is often provided as part of a curriculum development project, or it may be focused on a particular pedagogical approach or how standards should guide the alignment of instruction or assessment. 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 extend from biomedicine to nanotechnology and from physics to ecology. Some topics reflect national standards while others do not, and the content 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). A 2008 NSF workshop on NSF Summer Institute in

Applied Biotechnology & Bioinformatics at the University of California-Davis, on the other hand, promoted new hi-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.). These workshops provide a menu of choices for discerning professional development consumers. The theory of action rests on drawing interested teachers out of the context of everyday practice in order to provide intensive experience with new science concepts and practices.

The *school* itself is absent from the theory of action that drives many science education reform efforts. Summer institutes and workshops are typically offered at sponsoring university or research institutes (Westerlund et. al., 2002). These activities remove participating teachers from the school setting for a period of time ranging from hours to days. Institutes and workshops 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.

Research on effective professional development for teachers finds that 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 to for integrating new ideas into the contexts in which teachers' actually work to have significant and sustainable effects.

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 reform theory of action 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 have been identified at the levels of policy and research, 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. We argue that this theory of action is flawed, and that these leverage points are insufficient to enact substantive change. Reform policies established 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 a 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.

3. 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 classroom science teaching and learning is the responsibility of school and district leaders. K-12 school leaders, such as principals, instructional coaches, lead teachers, department heads and district curriculum leaders, establish the conditions for improving student learning (Spillane, Halverson & Diamond, 2004). Teachers, by themselves, can and often do initiate innovative practices for teaching and learning. But without 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. Implementing systemic change in science teaching and learning requires the active collaboration of the leaders who are responsible for improving the school instructional system. Whether they promote innovation through standards, curricula or professional development, science education reformers can only be successful if they design for the world in which school leaders and teachers work. And, most importantly, the conditions that make innovative science teaching and learning possible have little to do with the content or the pedagogies of innovative science initiatives.

School leaders act as gateway custodians for ideas and practices for systemic school improvement. 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, however, are not always perceived as innovators – the structures and processes they control are perhaps more frequently seen as conservative and resistant to change rather than friendly to reform. This perception results in part from the highly constrained design spaces in which leaders work. School leaders work in complex *systems of practice* composed of structures and priorities that are themselves the result of prior decisions about the organization of teaching and learning (Halverson, 2003). Many features of a school's system of practice are beyond the power of the school leaders and teachers to change. For example, practices such as 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 experience 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 woven together over time, they form a resilient system of practice that proves remarkably resistant to change.

District and school leaders create the space for instructional change in by addressing or co-opting the external pressures that bear most heavily on their school. Many leaders become so focused on responding to these pressures that they exercise their power and responsibility to create the impression of compliance with policy demands while avoiding significant changes to instructional program (Spillane, 2004). 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 rises to top of their priority lists.

In the following pages, we discuss the different ways in which the science education reform agenda is filtered through the policy pressures that operate at different levels of the educational system. 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 conservatizing pressure from empowered parents who are driven by their interpretation of college admissions expectations. At first glance it may seem that these pressures effectively stifle the space for science education reform. However, our discussion will point to areas that science reformers can exploit within the current contexts of reform to further the goals of innovative science education.

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). 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 of 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.

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 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. State test information 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 development of local formative assessment practices often involves teachers sharing existing quizzes and homework, and discussing quality standards with colleagues (Newmann & Wehlage, 1993). This process of enriching instructional practices with formative assessments give 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 to make a difference for students. In response to that need, many elementary schools have made headway towards student learning goals, 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, Prichett and Watson, 2007; Blanc, Christman, Hugh, Mitchell & Travers, 2009). While some of the research on coaching initiatives find 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 draw on teachers and other professionals trained in new practices, both through advanced degree programs and through participation in professional learning opportunities, to push existing school professional expertise and to catalyze new opportunities for interested professionals in the school to acquire useful knowledge and skills. Second-order learning environments go beyond disseminating new ideas to developing processes for participants. The best professional communities allow teachers 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 new practices improve student learning. Second-order environments provide an occasion for teachers to get new ideas conversation with colleagues and to sharpen practices through collaborative experimentation. Professional communities provide a path for leaders to distribute existing expertise and to catalyze 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. However, school leaders across the country have adopted a theory of action to create professional communities that allow teachers to use formative measures of learning to experiment with new ideas for improving student learning. For example, elementary school science reforms 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, science educators can learn from how school leaders structure professional communities to amplify expertise in mathematics and the language arts. This means developing benchmark science assessments that spark deep insights for students and teachers, and fostering in-school professional community to try out new practices and to discuss the results of these assessments. By aligning their efforts with the theory of action that guides literacy and mathematics education, science educators may be able to make the practices schools have developed to meet 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 narrowly defined 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.

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 successfully modify their teaching. Still, their reform efforts depended on teachers willing to take on informal leadership responsibilities who often found themselves in conflict with formal school leaders. Without such risk-taking informal leaders, academic departments can simply reinforce teacher autonomy and make 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). The first group, those for whom high school is a path to college, expects 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 remains substantively unchanged.

States reinforce the traditional course sequence by increasing science course requirements for graduation. By 2006, 40% of US states had raised graduation requirements in "higher-level" science courses, a category that includes 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.[2] 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" 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 focus on narrowly defined 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.

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 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. The margins of the comprehensive high school instructional program have always been a rich source of innovative practices (Powell, Farrar & Cohen, 1986). Reformers often dismiss these innovations on the ground that they have not "gone to scale", but leaders for science education reform can learn from the theories of action that guide marginal innovations. 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 composed of a series of traditional science and math classes with 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 in math and science than peers on a NAEP-referenced test, and that PLTW students were more likely to complete four years of math than their peers. Phelps, Camburn and Durham (2009) reported 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 outline 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 described 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 participant schools. PLTW 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 also 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.

4. 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. We describe four "leverage points": connecting teachers with each other, connecting teachers with resources, protecting the early stage of innovations, and building the subject-matter capacity of teachers. For each leverage point, we suggest ways that reformers *outside* of schools can support school leaders in enacting change.

Connect Teachers with Each Other

The development of professional community of teachers is 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. 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). Although developing and using teacher leaders requires time (i.e., release from normal classroom responsibilities) and training to achieve results, school leaders may have a greater impact by choosing a qualified and competent teacher leader and freeing up his or her time 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. This would both improve their own understanding of innovation and signal their support for ambitious changes in classroom practice (Gerard, Bowyer & Linn, 2008). Once reforms are underway, however, school-level leaders should avoid becoming intimately involved with reform efforts for the same reasons that senior managers in a corporate setting avoid becoming deeply involved in any single product or initiative. 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 become content leaders in science education reform (Wisconsin Department of Public Instruction, 2006).[3] On the other hand, leaders are ideally positioned to identify teachers who can take a stronger role in leadership practices. Reformers should promote the use of distributed leadership strategies, in which leaders delegate some responsibility for school-wide instructional reform to teachers. Distributing leadership responsibilities to specialists, coaches and department chairs gives teachers a share in the authority 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. 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-based theory of action for science education reform is to link teachers with curricular and community resources. 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 connect with cutting edge professional development or curriculum projects. Savvy leaders in high-poverty schools can develop research partnerships to 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. One of the lessons that teachers, leaders and reformers have drawn from the NLCB era is the utility of restructuring internal instructional practices to meet testing standards. Meeting the demands of high-stakes accountability has created a new market for assessment products (Burch, 2009). 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). The Full Option Science System (FOSS) provides an example of how assessment tools can be integrated into an inquiry-based science curriculum.[4] 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. Reform-oriented researchers should develop new, integrated approaches to assessment that support rather than compete with instructional innovation.

Protect Innovations During the Early Stages

A third central feature of a school-based theory of action for science education reform is an understanding of the developmental stages of innovation. Although a great deal has been written about the success or failure of educational reform efforts, much of that literature has focused on comprehensive school reform (CSR), rather than the specific issue of school level science education reform, with its unique opportunities and challenges. Still, many of the lessons from CSR at the state or national scale are also applicable to school-based science education reform. Larry Cuban's 1998 essay about success and failure in CSR 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.

Both of these problems (early judgments of success or failure and conflicting definitions of success) are pitfalls for local, science-specific reform as well. 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.

At a practical level, protecting new 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. Unless school-level leaders are willing to build a firewall around new innovations, encouraging teacher-led reform projects may simple set teachers up for failure. 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.

Build the Subject-Specific Competence of Teaching Staff

We have already recommended that reformers can 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 through alternative certification processes. 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 how practicing scientists were trained. 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 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 will inevitably encounter challenges from parents and community members who dispute the merits of innovative strategies relative to more traditional science pedagogy. 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). In the context of a strong and supportive teacher community, reformers should encourage school-level leaders to consider recruiting teachers with strong science preparation through alternative certification pathways. 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 theories of action that often guide science education reform efforts 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.

Notes

1. One useful tool for analyzing textbooks is the Project 2061 textbook evaluation criteria that they used in their own study of curriculum materials and that are available to the public on their web site (http://www.project2061.org/publications/textbook/hsbio/report/analysis.htm)

2. 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

3. 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.

4. For more detail please see: http://www.fossweb.com/

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