

Is There a Shortage Among Mathematics and Science Teachers?¹

Findings show that contrary to conventional wisdom, the problems schools are having staffing classrooms with qualified teachers are not due to increases in student enrollment or increases in teacher retirement. An argument is made that educational policy initiatives will not solve school staffing problems if they do not address the problem of teacher retention.

Introduction

Few educational problems have received more attention in recent years than the failure to ensure that elementary and secondary classrooms are all staffed with qualified teachers. Severe teacher shortages, education researchers and policy makers have told us, are confronting our elementary and secondary schools. At the root of these problems, we are told, is a dramatic increase in the demand for new teachers primarily resulting from two converging demographic trends—increasing student enrollments and increasing teacher turnover due to a “graying” teaching force. Shortfalls of teachers, the argument continues, are forcing many school systems to resort to lowering standards to fill teaching openings, inevitably resulting in high levels of underqualified teachers and lower school performance (e.g. National Commission on Excellence in Education 1983; National Academy of Sciences 1987; National Commission on Teaching 1997). These researchers and policy analysts have also stressed that shortages will affect some teaching fields more than others.

Special education, math and science, in particular, have usually been targeted as fields with especially high turnover and those predicted most likely to suffer shortages (e.g. Murnane et al. 1991; Boe, Bobbitt and Cook 1997; Grissmer and Kirby 1992, 1997; Weiss and Boyd 1990). As a result, over the past decade the inability of schools to adequately staff classrooms with qualified teachers (hereafter, school staffing problems) has increasingly been recognized as a major social problem, has received widespread coverage in the national media, and has been the target of a growing number of reform and policy initiatives.

The prevailing policy response to these school staffing problems

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has been to attempt to increase the quantity of teacher supply. In recent years a wide range of initiatives have been implemented to recruit new candidates into teaching. Among these are career-change programs, such as “troops-to-teachers,” designed to entice professionals into mid-career switches to teaching and Peace Corps-like programs, such as Teach for America, designed to lure the “best and brightest” into understaffed schools. Many states have instituted alternative certification programs, whereby college graduates can postpone formal education training and begin teaching immediately. Financial incentives, such as signing bonuses, student loan forgiveness, housing assistance and tuition reimbursement have all been instituted to aid recruitment (for a review of these initiatives, see, Hirsch, Koppich and Knapp 2001). The federal “No Child Left Behind Act,” passed in winter 2002, provides extensive funding for such initiatives.

Concern over school staffing problems has also given impetus to empirical research on teacher shortages and turnover. However,

¹ This article draws from a chapter that appeared in *Science Teacher Retention: Mentoring and Renewal*. Edited by J. Rhoton and P. Bowers. Arlington, VA: National Science Teachers Association (2002).

as numerous analysts have noted, it was difficult, initially, to study these issues because of a lack of accurate data, especially at a nationally representative level, on many of the pertinent issues surrounding teacher supply, demand and quality. In order to obtain such data, the National Center for Education Statistics (NCES), the statistical arm of the U.S. Department of Education, designed the Schools and Staffing Survey (SASS) and its supplement, the Teacher Followup Survey (TFS), in the late 1980s.

The Project

Over the past decade I have been undertaking research using SASS and TFS to study a number of issues concerned with teacher supply, demand and quality (for summaries, see Ingersoll 1999, 2001a, 2001b). In this article I will briefly summarize what the data tell us about the realities of school staffing problems and teacher shortages, especially for math and science teachers. I will argue that the conventional wisdom on teacher shortages is largely a case of a wrong diagnosis and a wrong prescription and that while the above policy efforts are often worthwhile, the data show they will not solve the teacher staffing problems schools are facing.

SASS and TFS are the largest and most comprehensive data source available on the staffing, occupational, and organizational aspects of schools. SASS administers survey questionnaires to a random sample of about 52,000 teachers from all types of schools and from all 50 states. NCES has administered SASS on a regular basis; to date, four cycles have been completed — 1987-88; 1990-91; 1993-94; 1999-2000. In addition, all those teachers who left their teaching jobs in the year subsequent to the

administration of the initial survey questionnaire are again contacted to obtain information on their departures. This supplemental study—the TFS—is the largest and most comprehensive data source on teacher turnover in the U.S.

The data presented here come primarily from the two most recent cycles of the TFS (1994-95 and 2000-01; the last cycle of TFS was not entirely released as of fall 2002) and represent all teachers for grades k through 12 and from all types of schools, both public and private. Math and science teachers, the primary focus of this article, are those identified by their principals as having their main teaching assignment in either math or science and represent about 11 percent of the total teaching force. About 22 percent of these math/science teachers are employed in elementary or middle schools, another 73 percent are in

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secondary schools and about 5 percent are in combined (k-12 grades) schools. Throughout, I will compare the data on math/science teachers with the data for all teachers. (For information on the TFS see, Whitener et al. 1997.)

There are two types of teacher turnover from schools. The first, often called teacher attrition, refers to those who leave the occupation of teaching altogether. The second type, often called teacher migration, refers to those who transfer or move to different teaching jobs in other schools. Research on teacher supply and demand has often emphasized the first type and neglected the second type. Many assume that teacher migration is a less significant form of turnover because it does not increase or decrease the overall supply of teachers, as do retirements and career changes and, hence, assume it does not contribute to the problem of staffing schools and does not contribute to overall shortages. From a systemic point of view, this is probably correct. However, from the viewpoint of those managing schools, teacher migration and attrition have the same effect — in either case it results in a decrease in staff, which usually must be replaced. Hence, from the school's perspective, teacher migration can, indeed, contribute to the problem of keeping schools staffed with qualified teachers. For this reason, this article will present data on both teacher migration and teacher attrition. Hereafter, I will refer to teacher migration as “movers,” teacher attrition as “leavers” and total turnover as “departures.”

In the next section I will present data on how many teachers depart from their teaching jobs, how these rates compare with some other occupations and establish the importance of teacher turnover for teacher shortages. In

the following section I will present statistics on the reasons why teachers move from or leave their teaching jobs. These latter data are drawn from items in the TFS questionnaire that ask teachers to indicate the reasons (up to three) for their departures, from a list provided in the survey questionnaire (see appendix). In addition, I present data from an additional set of items that asks teachers to indicate the sources (up to three) of their dissatisfaction, if they had indicated dissatisfaction either with teaching, with their school or with their salary as a reason for their turnover. Finally, I conclude by briefly discussing the implications of these findings for understanding and addressing the staffing problems of schools.

Results

The Importance of Teacher Turnover for Teacher Shortages

Consistent with shortage predictions, the data show that the demand for teachers has indeed increased. Since 1984, student enrollments have increased, teacher retirements have also increased, most schools have had job openings for teachers and the size of the elementary and secondary teaching workforce has increased. More important, the SASS data tell us substantial numbers of those schools with teaching openings have experienced difficulties finding qualified candidates to fill their positions.

But, the data also show that the demand for new teachers and subsequent staffing difficulties are not primarily due to student enrollment and teacher retirement increases. Most of the demand and hiring is simply to replace those who recently departed from their teaching jobs and, moreover,

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most of this teacher turnover has little to do with a “graying workforce.”

Teaching is a relatively large occupation — it represents 4% of the entire nationwide civilian workforce. There are, for example, over twice as many k-12 teachers as registered nurses and five times as many teachers as either lawyers or professors (US Bureau of the Census 1998). Moreover, the rate of turnover for teachers appears to be higher than in many other occupations. One of the best known sources of national data on rates of employee turnover, the Bureau of National Affairs, has shown that nationwide levels of employee turnover, gathered from a wide range of occupations, have been quite stable over the past decade; averaging 11.9 percent per year (Bureau of National Affairs 2002). The employee turnover rate provides a rough benchmark; comparison of the TFS data with the rate for employees in general suggests that teaching has a relatively high turnover rate: 14.5 percent in 1988-89; 13.2 percent in 1991-92; 14.3 percent in 1994-95 and 15.7 percent in 2000-01 (see Figure 1). Total teacher turnover is about evenly split between movers and leavers; in 1994-95 7 percent of teacher turnover was migration and 7.3 percent was attrition.

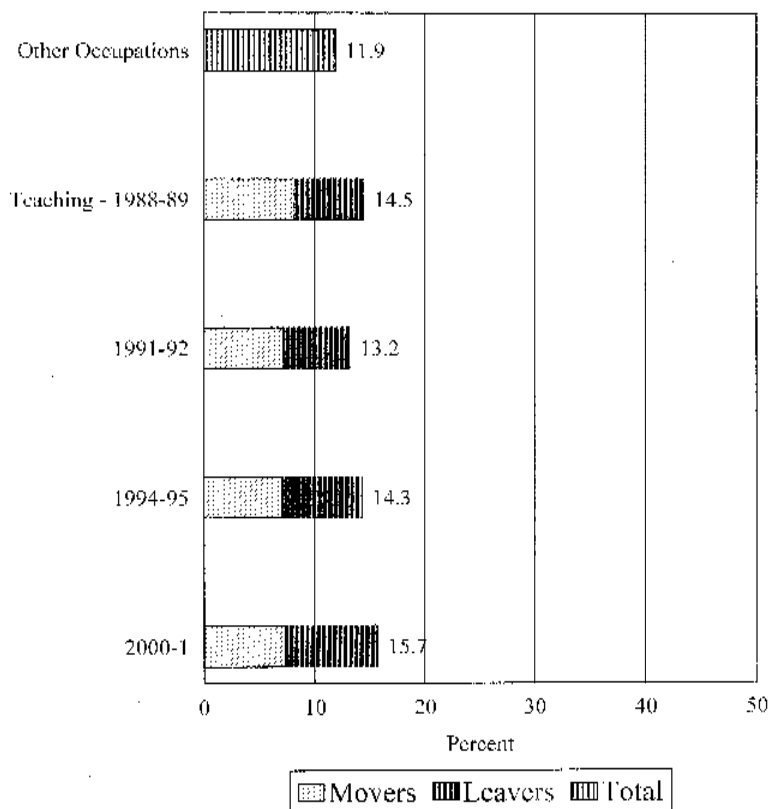
The sheer size of the teaching force combined with the relatively high annual turnover of the teaching occupation means that there are

relatively large flows in, through, and out of schools each year. For instance, the SASS/TFS data show that about 535,000 teachers (including within-district school-to-school transfers) entered schools just prior to the 1999-2000 school year. But, in the following 12 months even more — about 540,000 teachers — departed their jobs. In other words, in that 12-month period over a million teachers — almost one third of the teaching force — were in job transitions. The image that these data suggest is one of a “revolving door.”

Of course, not all teacher or employee turnover is detrimental. There is an extensive research literature on employee turnover conducted by those who study organizations and occupations in general (e.g., Price 1977; Mobley 1982). On the one hand, researchers in this tradition have long held that a low level of employee turnover is normal and efficacious in a well-managed organization. Too little turnover of employees is tied to stagnancy in organizations; effective organizations usually both promote and benefit from a limited degree of turnover by eliminating low-caliber performers and bringing in “new blood” to facilitate innovation. On the other hand, researchers in this tradition have also long held that high levels of employee turnover are both cause and effect of performance problems in organizations (Price 1989).

From this organizational perspective, employee turnover is especially consequential in work sites, like schools, which have “production processes” requiring extensive interaction among participants (Lortie 1977; Ingersoll 2003). Such organizations are unusually dependent upon commitment, continuity and cohesion among employees and, hence, especially vulnerable to

Figure 1 – Percent annual employee turnover and percent annual teacher turnover



Source: Teacher Followup Survey and Bureau of National Affairs

employee turnover. Hence, from this perspective, high turnover of teachers from schools is of concern not simply because it may be an indicator of sites of potential staffing problems, but because of its relationship to school performance. Moreover, from this perspective high rates of teacher turnover are of concern not only because they may be an indication of underlying problems in how well schools function, but also because they can be disruptive, in and of themselves, for the quality of school cohesion and performance.

However, while the data show that teaching has relatively high turnover,

the data also show that the revolving door varies greatly among different kinds of teachers. Notably, the turnover rate for math/science teachers is higher than for teachers in a number of other fields (see figure 2). Moreover, as found in previous research (Murnane et al. 1991), the TFS data show that teaching is an occupation that loses many of its newly trained members very early in their careers—long before the retirement years. I used the TFS data to provide a rough estimate of the cumulative attrition of beginning teachers from the occupation in their first several years of teaching. The data suggest that after just five years,

between 40 and 50 percent of all beginning teachers have left teaching altogether.

In short, the demand for new teachers, and the subsequent problems schools face ensuring classrooms are staffed with qualified teachers, are to a significant extent due to teachers moving from or leaving their jobs at higher rates than in many other occupations. These patterns are chronic — similar results are found in all four cycles of the TFS data from the late 1980s to 2001.

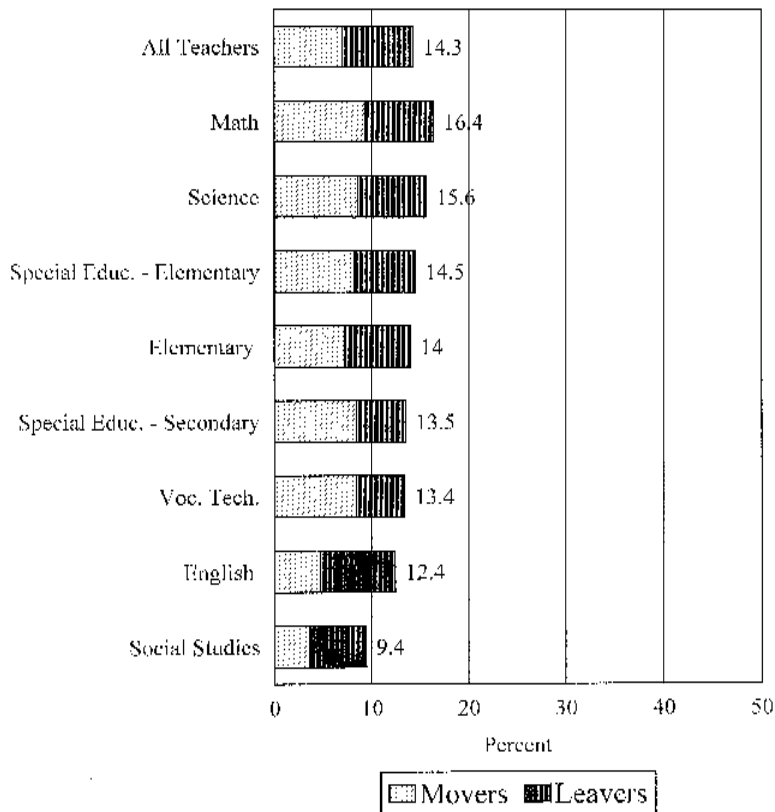
These data raise an important question: why do teachers depart their jobs at relatively high rates?

The Sources of Teacher Turnover

This next section turns to the reasons behind teacher turnover, especially among math and science teachers. Table 1 lists the data on teachers' reasons for their turnover, separately for all teachers and for math/science teachers and also separately for movers and leavers. Note that the column

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Figure 2 – Percent annual teacher turnover, by field



Source: 1994-95 Teacher Followup Survey

segments in table 1 displaying percent teachers giving various reasons for turnover each add up to more than 100 percent, because respondents could indicate up to three reasons for their departures. The same applies to the columns displaying reasons for dissatisfaction-related turnover. These same data (but with movers and leavers combined) are also more succinctly illustrated in Figures 3 and 4.

As illustrated in Figure 3 and Table 1, overall, math/science teachers do not greatly differ from other teachers in the reasons why they depart from their teaching jobs. Contrary to conventional wisdom, retirement is not an especially

prominent factor. The latter actually accounts for only a small part (13%) of total turnover. Of course, if one focuses on attrition alone (only those leaving teaching altogether) retirement is more prominent because, by definition, migration excludes retirement. Even in this case, however, retirement is not an especially prominent factor; retirement accounts for only a quarter of leavers (25%). Notably, retirement also does not account for the relatively high rates of turnover by math/science teachers.

School staffing cutbacks, due to lay-offs, school closings and reorganizations, account for a larger

proportion of total turnover than does retirement. Staffing actions more often result in migration to other teaching jobs rather than leaving the teaching occupation altogether (34% of migration and 8% of attrition).

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Personal reasons, such as departures for pregnancy, child rearing, health problems and family moves are more often given as reasons for turnover than are either retirement or staffing actions (36 percent of migration and 44 percent of attrition).

Finally, two related reasons are, collectively, a very prominent source of turnover. About half of all teachers who depart their jobs give as a reason either job dissatisfaction or the desire to pursue another job, in or out of education. Notably, math/science teachers are significantly more likely to move from or leave their teaching jobs because of job dissatisfaction than are other teachers (40 percent of math/science and 29 percent of all teachers).

As illustrated in Figure 4 and Table 1, of those who depart because of job dissatisfaction, the most common reasons given are: low salaries; a lack of support from the administration; student discipline problems; lack

Table 1 - Percent Teacher Turnover and Percent Teachers Giving Various Reasons for their Turnover

	All Teachers		Math and Science Teachers	
	Movers	Leavers	Movers	Leavers
Rates of Turnover	7	7.3	9	7
Reasons for Turnover				
Retirement	-	25	-	26
School Staffing Action	34	8	28	11
Family or Personal	36	44	32	45
To Pursue other Job	29	25	33	21
Dissatisfaction	32	25	48	28
Reasons for Dissatisfaction				
Poor Salary	49	61	53	66
Poor Administrative Support	51	32	57	22
Student Discipline Problems	22	24	33	21
Lack of Faculty Influence & Autonomy	18	15	11	15
Poor Student Motivation	12	18	17	32
Poor Opportunity for Professional Advancement	8	5	4	1
Inadequate Time to Prepare	5	6	3	6
Intrusions on Teaching Time	5	11	6	12
Class Sizes too Large	3	11	.5	9

of student motivation; and lack of influence over school decision making. Moreover, several factors stand out because few teachers tie them to their turnover: large class sizes; intrusions on classroom time; lack of planning time; and lack of opportunity for professional advancement.

I have found these findings to be true across different cycles of the data and across different subsets of teacher turnover. For example, in general, similar kinds of dissatisfactions lie behind both teacher migration and teacher attrition. Further analyses of the TFS migration data show that there

is a strong flow of teachers from more desirable to less desirable schools. After controlling for the type of school, four factors stand out as related to both teacher migration and attrition: schools with low salaries, student discipline problems, little support for new teachers and little faculty input into school decision making tend to lose teachers to schools without these problems.

In sum, the data indicate that math/science teachers, like other teachers, depart their jobs for a variety of reasons. Retirement accounts for a relatively small number of total departures,

a moderate number of departures are due to school staffing actions, a large proportion indicate they depart for personal reasons, and a large proportion also report they depart either because they are dissatisfied with their jobs or in order to seek better jobs or other career opportunities.

Implications

Since the early 1980s, educational policy analysts have predicted that shortfalls of teachers resulting primarily from two converging demographic trends — increasing student enrollments and increasing

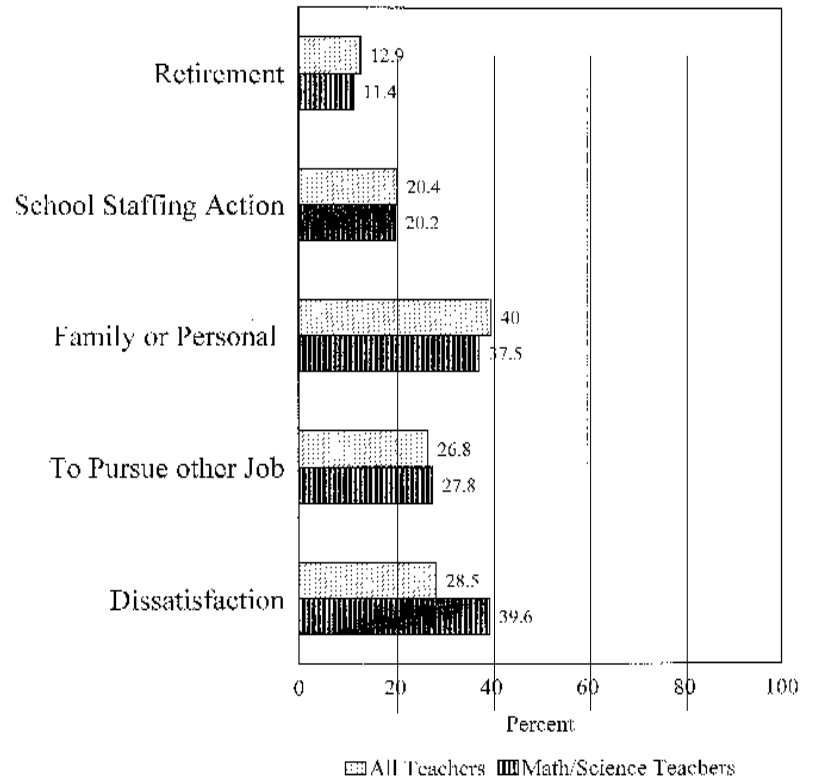
teacher retirements — will lead to problems staffing schools with qualified teachers and, in turn, lower educational performance.

This analysis suggests, however, that school staffing problems for both math/science and other teachers are not solely or even primarily due to teacher shortfalls resulting from either increases in student enrollment or increases in teacher retirement. In contrast, the data suggest that school staffing problems are also a result of a “revolving door” — where large numbers of teachers depart teaching for reasons other than retirement.

Teacher turnover is a significant phenomenon and a dominant factor driving demand for new teachers. The data show that, while it is true that student enrollments are increasing, the demand for new teachers is primarily due to teachers moving from or leaving their jobs at relatively high rates. Moreover, this analysis shows that, while it is true that teacher retirements are increasing, the overall amount of turnover accounted for by retirement is relatively minor when compared to that resulting from other causes, such as teacher job dissatisfaction and teachers seeking to pursue better jobs or other careers.

These findings have important implications for educational policy. Supply and demand theory holds that where the quantity of teachers demanded is greater than the quantity of teachers supplied, there are two basic policy remedies: increase the quantity supplied or decrease the quantity demanded. As noted in the beginning of this article, teacher recruitment, an example of the former approach, has been and continues to be a dominant approach to addressing school staffing inadequacies. However, this analysis suggests that recruitment programs

Figure 3 – Percent teachers giving various reasons for their turnover



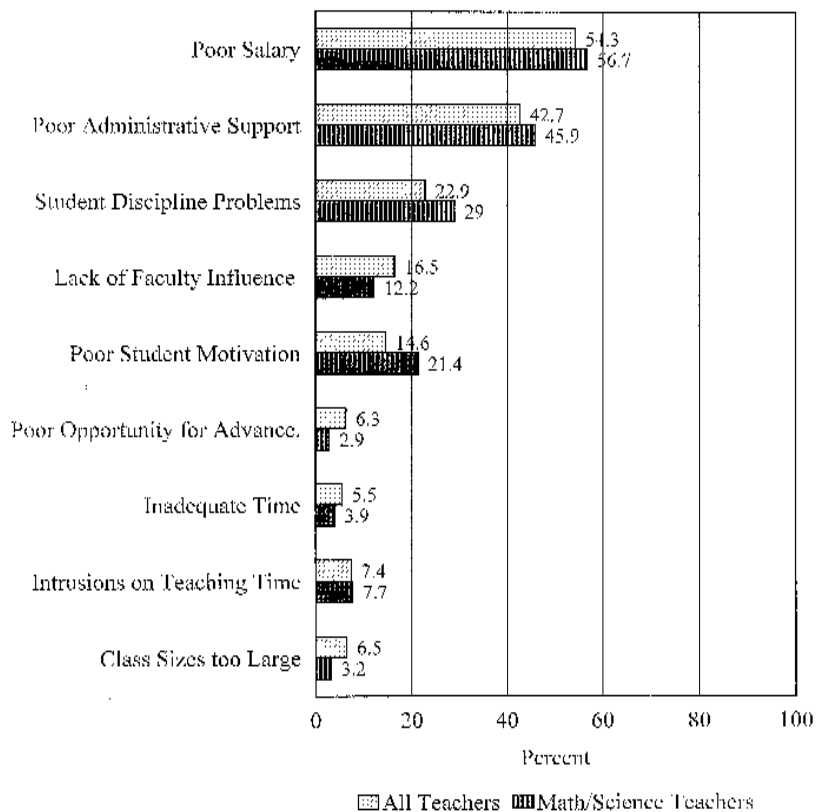
Source: 1994-95 Teacher Followup Survey

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alone will not solve the staffing problems of schools, if they do not also address the problem of teacher retention. In short, this analysis suggests that recruiting more teachers will not solve staffing inadequacies if large numbers of such teachers then prematurely leave.

What then can be done? From the perspective of this analysis, schools are not simply victims of inexorable demographic trends, and there is a significant role for the management of schools in both the genesis of and solution to school staffing problems. Rather than increase the quantity of teacher supply, an alternative

Figure 4 – Percent teachers giving various reasons for their dissatisfaction-related turnover



Source: 1994-95 Teacher Followup Survey

Rather than increase the quantity of teacher supply, an alternative solution to school staffing problems, documented by this analysis, is to decrease the demand for new teachers by decreasing turnover.

solution to school staffing problems, documented by this analysis, is to decrease the demand for new teachers by decreasing turnover. The data suggest that the way to improve teacher retention is to improve the conditions of the teaching job. Schools across the country where there is more support from the school administration for new teachers, such as induction and mentoring programs have significantly lower levels of teacher turnover. The same holds for schools with higher salaries, fewer student discipline problems, and enhanced faculty input into school decision-making. The

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data document that changing these things would all contribute to lower rates of turnover, in turn, diminish school staffing problems and, hence, ultimately, aid the performance of schools.

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Appendix

Definitions of Measures of Reasons for Turnover

In the TFS teachers could list up to 3 choices from a list of 12 reasons for their departures. I grouped the 12 reasons into 5 categories, as follows:

- **Retirement.**
- **School Staffing Action:** reduction-in-force/lay-off/school closing/reassignment.
- **Family or Personal:** family or personal move; pregnancy/child rearing; health; other family or personal reason.
- **To Pursue other Job:** to pursue another career; to take courses to improve career opportunities in or outside the field of education; for better teaching job.
- **Dissatisfaction:** dissatisfied with teaching as a career; dissatisfied with the school; for better salary or benefits.

Of those teachers who indicated dissatisfaction, as defined above, as a reason for their departure, they could list up to 3 choices from a list of 12 reasons for their dissatisfaction. I grouped the 12 reasons into 9 categories, as follows:

- **Poor Salary**
- **Poor Administrative Support:** lack of recognition and support from administration; lack of resources and material/equipment for your classroom; inadequate support from administration
- **Student Discipline Problems**
- **Lack of Faculty Influence and Autonomy:** lack of influence over school policies and practices; lack of control over own classroom
- **Poor Student Motivation:** poor student motivation to learn
- **Poor Opportunity for Professional Advancement**
- **Inadequate Time to Prepare:** inadequate time to prepare lesson/teaching plans
- **Intrusions on Teaching Time:** intrusions on teaching time (i.e. not enough time working directly with teaching students)
- **Class Sizes too Large**

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The Coupled-Inquiry Cycle: A Teacher Concerns-based Model for Effective Student Inquiry

The science education reform movement that emphasizes student-centered construction and meaningful understanding of science concepts, has identified inquiry teaching and learning as an effective strategy for student learning.

The National Science Education Standards (National Research Council, 1996) has become, arguably, the most important single influence in reshaping K-12 science instruction in the United States during the past several years. Central to their vision of effective science teaching and learning is the strategy of student-centered inquiry as the primary vehicle for students to develop meaningful understandings of key science concepts as well as learn about the nature and process of science.

During the past five years, in response to the strong emphasis on inquiry by the National Science Education Standards (NSES), I have been involved in developing and facilitating professional development workshops for K-12 science teachers on the use of inquiry strategies and practices for meaningful learning of science concepts. These workshops have been designed to model inquiry by doing hands-on investigations on a wide variety of physical, earth, and biological phenomena. In the workshops, these investigations are combined with reflection and discussion of both the inquiry experience and the vision for inquiry promoted by the

NSES and other science education literature. While participant response has been generally very positive about inquiry-style learning, there has also been a great deal of concern expressed about the actual implementation of this vision in the classroom.

As a result of the reflections and discussions with hundreds of K-12 teachers in more than 30 different workshops, a model of inquiry has emerged that seems to balance the vision of student-centered inquiry described in the NSES with an inquiry strategy that reflects teacher concerns. This model, called the Coupled Inquiry Cycle, combines, or “couples”, “teacher guided” inquiry with “full” or “open” inquiry, into an inquiry cycle based on a learning cycle format (Dunkhase, J.A., 2000; Martin-Hansen, L., 2001).

Inquiry and the National Science Education Standards (NSES)

“Inquiry into authentic questions generated from student experience is the central strategy for teaching science.” This powerful statement from the teaching standards section of the National Science Education Standards (NSES p. 31) illustrates the important

role inquiry plays in the NSES vision for science education reform. Inquiry is pervasive throughout the standards as the driving force for effective teaching and learning in science. From the teaching standards to the content standards, the assessment standards, and the professional development standards, inquiry is central to the mission of acquiring scientific literacy for all learners. To further reinforce the importance of inquiry as a learning strategy for scientific literacy, the National Research Council has subsequently published an additional volume entitled *Inquiry and the National Science Education Standards* which is dedicated specifically to elaborating on the inquiry standards (National Research Council, 2000).

What is Inquiry and Why is it so Important?

Historically, science instruction and the assessment of achievement in science, has focused on students acquiring the products of scientific inquiry – content knowledge – the all too familiar encyclopedic body of facts, formulas, definitions, and equations, to be memorized and regurgitated on the chapter-end or

semester-end quizzes and tests. This knowledge has not served the needs of most of our science students because they generally have not learned the science concepts meaningfully for understanding. As a result, students have not gained useful knowledge that is relevant to their lives or science understandings that help them make informed choices as scientifically literate citizens.

Inquiry, on the other hand, is a much more powerful way to learn science meaningfully. It focuses on content knowledge in the context of the process of developing scientific understanding. That is, it is a strategy for learning science concepts that are constructed by students doing science - "not something that is done to them" (NSES p20). This is not to be confused with learning "science process skills" or the "discovery" science teaching strategy of the '60's. It is also not simply doing experiments, hands-on activities, "labs", or "the scientific method". Rather, the NSES grade-level chapters on content standards define inquiry as a series of abilities and understandings that students should know and be able to do to develop BOTH the important products AND processes of the scientific endeavor.

While the inquiry abilities articulated in the NSES are slightly different for each grade-level cluster (K-4, 5-8, 9-12) there are basic elements of the inquiry vision that are common across all grade levels. These common abilities are modified somewhat to form the core of the coupled inquiry cycle and summarized in Table 1.

Why isn't inquiry eagerly embraced by teachers?

The science education reform community generally and enthusiastically advocates inquiry. In

Table 1. Inquiry Abilities

1. Asking a question about a natural phenomenon.
2. Designing an investigation to try and answer the question.
3. Conducting the investigation to collect data and evidence.
4. Using reason and logical thinking to interpret the evidence to create the best answer to the question.
5. Presenting the results of the investigation to the community.

spite of the well documented advantages and benefits of inquiry-driven learning for students (Shymansky, et. al., 1990) and despite attempts to promote some variation of inquiry in schools for the past 70 years, the actual practice of inquiry has rarely been successfully implemented by practicing teachers on a large-scale with long-term positive results (Yager, 1997). The reasons for this failure may be related to the concerns and perceptions of teachers charged with the task of making inquiry work in real classrooms. There appear to be several important issues and challenges related to the "comfort-zone" of teachers that need to be overcome in order for practicing teachers to implement the ideal of "full inquiry" as envisioned by the NSES. The concerns most often identified relate to "control issues" dealing with time, materials, safety, and curriculum goals (Anderson, 1998). Rightly or wrongly, the NSES vision of inquiry has often been perceived as being too "open", or too "student-driven", without enough teacher input into the direction and outcomes of inquiry investigations.

The Coupled Inquiry Cycle

During the course of designing and facilitating teacher inquiry workshops, the concerns voiced by participants, and reinforced by the research literature, led to the evolution of an inquiry model that addresses

many of the reservations teachers express about using inquiry as a teaching strategy in their classrooms. This model specifically addresses the issues of control over content and curriculum goals; teachers' need to "lecture" to make sure students "get it"; and control over safety, time, and materials. The coupled inquiry cycle endeavors to balance these needs, while still adhering to the vision of true student-centered "full" inquiry, by combining or "coupling" together "teacher guided" inquiries with "open" inquiries that are completely student-driven. These "coupled inquiries" (Figure 1) are embedded in a cycle based on traditional learning cycle models, such as the 5E model of Bybee (1997) and problem solving models, such as the Search, Solve, Create, and Share (SSCS) model (Pizzini, 1989). A description of the components of the coupled inquiry cycle is as follows:

1. Invitation to Inquiry: The "invitation" stage of the cycle is the motivator or "hook" activity designed to stimulate student interest in the topic or concept to be investigated. Rather than the teacher simply announcing that "today we're going to investigate soils" because it is next in the curriculum, the invitation stage of the cycle provides the opportunity for teachers to get the students personally involved and invested in the topic. Teachers can use demonstrations,

current events, field trips, guest speakers, and other mechanisms to help generate interest and excitement to help students become fully engaged in the pursuit of understanding that the inquiry learning process promotes.

Example: To begin a middle school-level inquiry cycle on force and motion, the teacher reads “Cosmo Zooms”, by Arthur Howard to the class. This is a book about a dog that learns to skateboard. The teacher then helps the students relate the story to their own experiences on skateboards, bicycles, and roller blades and probes their thinking about what factors influence how fast they might go down a hill. The teacher specifically asks the students to think about whether the weight of dogs (or kids) has a significant effect on the speed and write about their experience and thoughts on the subject in their journals or science notebooks. The cycle then proceeds to a guided balls and ramps investigation.

2. Guided Inquiry: The guided stage of the cycle provides the opportunity for

the teacher to direct students towards specific concept objectives that may be required by their curriculum or the NSES content standards. This gives the teacher control over where the initial investigation is going and what the outcomes will be. It has been found that this approach seems to fit well within teachers’ comfort zones. The “steps” in this inquiry are basically the same as those advocated in the NSES (Table 1, Figure 2) but in the Coupled Inquiry Cycle the teacher structures both the question and the investigation (Table 2). Traditional lab activities teachers have used successfully can be modified slightly to provide effective guided inquiries. Even though there is significant teacher direction in structuring the inquiry, the inquiry is still strongly student-centered (Table 2) in that the students conduct the investigation, interpret the results, and create presentations to explain their findings.

Example: Based on curriculum objectives related to relevant NSES

grade-level content standards and Project 2061 benchmarks related to force and friction, the teacher structured an investigation for the learners to investigate the question: Do heavy balls or light balls roll down a ramp fastest? After individually predicting which balls might be fastest and slowest, and giving their personal explanations for their predictions, the students are grouped into small teams of 3 or 4 and given a set of six – 1” balls of different weights that are carefully chosen so that the frictional effects of their surfaces have been minimized. The students roll each of the balls down the ramp and time them for five trials to test their predictions. They then graph and analyze their data, compare it to their predictions, and create a presentation to communicate their results to the class to explain what happened and why. Students are often surprised at the results and lively class discussions follow. It should be noted that this guided inquiry is simply a slightly modified version of a standard classroom activity.

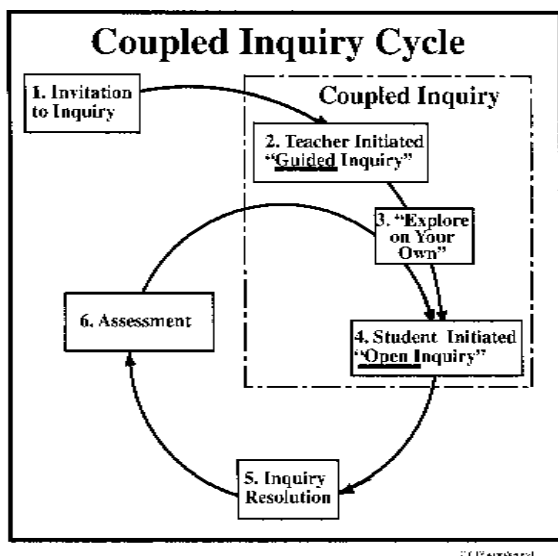


Figure 1
Complete Coupled Inquiry Cycle Model

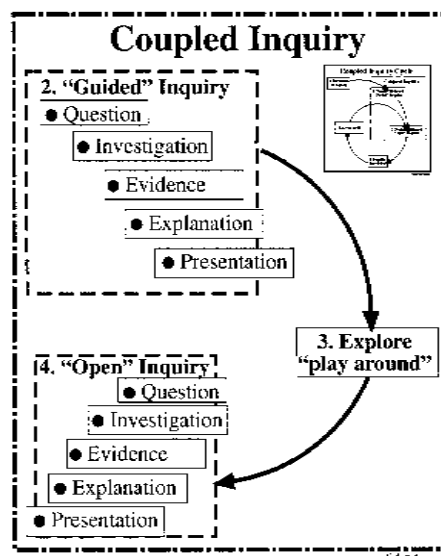


Figure 2
Details of the Coupled Inquiry Stages of the Cycle

3. “Explore on your own”: This may be THE most important stage of the coupled inquiry cycle because it explicitly promotes the curiosity of the learners by encouraging them to personally explore the phenomena of interest. Here the investigators are allowed to explore, or “play around” with the materials used in the guided investigation and most importantly, to generate their own questions that might be investigated in the next stage of the cycle—the open inquiry. This provides the critical link between the guided inquiry and open inquiry to follow.

Example: After the presentations and discussions related to the guided inquiry are finished the students are eager to investigate the balls and ramps phenomena further. They generally have many ideas and questions about what is usually a discrepancy between what they thought would happen and what actually occurred. The teacher has made some additional materials available for the students such as more ramp lengths, balls of different diameters, balls with different surfaces, other timing devices, etc. The “explore on your own” stage of the cycle gives the students the opportunity to “play” with the materials to try out some of their own ideas preliminarily and informally and to generate additional

questions much in the same way scientists often do when they are exploring a new idea or phenomena before they begin a formal research project. After allowing the students a reasonable amount of time exploring in this stage of the cycle (as determined by the teacher), the student groups are asked to list their “burning questions” and come to consensus as to which one or ones they want to investigate.

4. “Open” Inquiry: The “open” or “full” inquiry is intended to be totally student-centered and fully reflect the vision of inquiry discussed in the NSES. Here, questions generated in the “explore on your own” stage are discussed by student investigators and the teacher. Questions are negotiated and selected for further investigations that are reasonable in the context of the curriculum, time, materials, and safety concerns as discussed earlier. Students then design the investigations, conduct and interpret the study, and finally share their results with the teacher, the rest of the class, and/or the community (Table 2 and Figure 2).

Example: The students are now asked to take their designated question and refine it into one that is clear and can be investigated using available classroom materials. Students then

design their own investigations, carry them out, analyze their data, and present the evidence and explanations to the class.

Teachers often find that for themselves and their students, this is the most interesting and exciting part of the cycle because the richness of student thinking about the topic becomes apparent. Contrary to what teachers sometimes expect, the questions and investigations students generate will generally be very productive extensions of the teacher’s initial guided inquiry. Often, however, the students’ questions and findings will be something the teacher never anticipated and the both the students and teachers are rewarded by learning something new. This is the real “payoff” in excitement and satisfaction for the teacher that is rarely, if ever, experienced in traditional textbook driven classrooms.

5. Inquiry Resolution: One of the concerns many teachers express about inquiry is that they don’t feel “comfortable” that students have learned anything at the end of student-generated investigations. The inquiry resolution stage of the cycle is intended to provide an opportunity for the teacher to help students come to some cognitive closure regarding the target

Table 2 – Comparison of Inquiry Responsibilities

NSES Inquiry Ability	Guided Inquiry Stage	Open Inquiry Stage
Whose responsibility is it to:		
1. Ask the question to be investigated.	Teacher	Student
2. Plan the Investigation.	Teacher	Student
3. Conduct the Investigation to collect data.	Student	Student
4. Construct explanations from the data.	Student	Student
5. Communicate the results of the investigation.	Student	Student

science concepts and satisfy the curriculum objectives. The teacher can review the student inquiry presentations for common understandings; ask students what they've learned and what they would investigate next; do a demonstration that challenges or supports student findings; or even do some direct instruction if necessary, to clarify the science content. And, importantly, inquiry resolution is a perfect time to discuss applications of the science concepts and inquiry results to the students' lives.

Example: At the end of the student presentations and ensuing discussions, the teacher realized that even though the students had constructed the important understanding that the weight, or mass, of the ball doesn't significantly influence its acceleration down the ramp, they still don't understand that friction is a force and that changes in motion are related to forces. The teacher then did some "direct instruction" and a demonstration to clarify the definitions and concepts of force and friction; how they relate to changes in motion; and another inquiry for the students to investigate these concepts further.

6. Inquiry Assessment: Formative assessment should be occurring during all parts of the inquiry cycle. This process is important to inform the teacher about the progress the students are making and what content issues or questions might be addressed by "direct instruction" in the inquiry resolution stage discussed above. It is also often valuable to do a summative evaluation assessment at the end of the cycle. Even though summative assessment might be used for evaluation purposes, ideally it also should have some kind of "authentic"

or "performance" component rather than simply being a traditional paper and pencil test. This might involve having students apply their knowledge of target concepts to a problem-solving activity or creating a need for them to use the knowledge in a personal or societal decision context—the scientific literacy and informed decision making assessment. This assessment stage should also be structured in a way that is useful in initiating additional inquiries to continue the cycle as time and curriculum pressures permit.

Example: As students have been doing their investigations the teacher, as part of the inquiry facilitation process, has been informally monitoring the students and helping them by asking probing questions and making subtle suggestions. During the guided and open inquiry presentations a rubric that was generated by the students and the teacher was used to assess for both their content understandings and inquiry abilities. Finally, the teacher gave them an authentic/performance assessment problem to solve using a real Tonka-toy dump truck to haul bricks down a hill (plywood ramp) to see if the students could transfer their knowledge to a novel situation.

Conclusions

During the course of the past several years the coupled inquiry cycle model has been used in many professional development workshops for science teachers. Discussions during the workshops, as well as written workshop evaluation feedback, suggest that this model successfully addresses teacher concerns about using inquiry as a strategy for meaningful learning of science content. Coupled inquiry workshop participants indicate that they are more likely to apply inquiry

in their classrooms than participants in similar inquiry workshops that focused only on the strictly student-centered "full" inquiry model. This is in concert with the findings of Hall and Hord (1987) who found that for effective change to occur in the classroom the process must reflect the concerns of the participants most directly implementing the change.

It is not intended that the coupled inquiry cycle be strictly interpreted or rigidly applied. Science content doesn't have to be addressed only after the open inquiry - some can be addressed before or during the inquiries as well. The "explore on your own" phase can be, and often is, an on-going process throughout the inquiry process for many students. And certainly, assessment could and should be present throughout the cycle. This model is suggested as a starting point to provide a teacher-friendly structure that can be modified as appropriate by the teacher. There is no absolute right or wrong way to apply the coupled inquiry model and there is no implication that an effective science learning environment requires "all inquiry all the time." For teachers who want to try student-centered inquiry in their classrooms but are hesitant for reasons discussed above, coupled inquiry can provide a framework for a successful experience for both students and teachers.

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Science in the City: Consistently Improved Achievement in Elementary School Science Results from Careful Planning and Stakeholder Inclusion

Setting high expectations in science education in the elementary grades, leading to increasingly improved achievement for both poor and minority students, is being demonstrated convincingly by a large urban school district.

Introduction

Our future depends upon a strong, competitive workforce and upon citizens equipped to function in a world of great and growing complexity. Central to producing such results is a system of education that specifies what every student in each grade should know and be able to do in both mathematics and science. Educational excellence in these disciplines improves more than just the health of the disciplines themselves. It also improves the everyday lives and productivity of those who see the world through eyes enlightened by a knowledge of math and science. But America's world leadership in innovation is jeopardized if schools fail to respond to this challenge. Although educational leaders acknowledge these facts, a dangerous movement is stirring, determined to water down or even eliminate science instruction in elementary schools.

On January 8, 2002, President George W. Bush signed into law the No Child Left Behind (NCLB) Act, the sweeping new federal education

reform bill that will affect virtually every aspect of K-12 education. NCLB raises accountability in math and reading skills for students, teachers, and administrators; beginning in SY 2005-2006, the law requires annual testing of both subjects in each grade from grades 3 through 8. Each of us involved in science education has almost certainly started to feel the downside of the law's initial emphasis on math and reading. NCLB's immediate adverse effects are evident

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whenever we are forced to defend science education against a rising swell of attempts by local districts to devote ever more time to the two tested disciplines, or to defend it against national efforts to abandon science altogether in grades K through 6.

Eventually, however, NCLB may actually benefit science education, although not immediately. Beginning in SY 2007-2008, NCLB requires all states to begin testing science annually in one grade in each of three grade ranges: 3-5, 6-9, and 10-12. But the sad truth is that, until then, teachers will teach only that which gets tested and administrators will promote only that which is needed to keep their schools off the list of underachieving schools.

Challenges to Our Schools

The growing numbers and percentage of our citizens who come from racial/ethnic minority groups, combined with gaps in achievement between majority and minority students, pose serious challenges to our schools. To counter these challenges, we must resolve to improve science

programs at all levels if we hope to be able to supply professionals who are literate in those topics of science, technology, and mathematics so critical to our need for an expanding work force in the fields of science and engineering. In the next decade, the total U.S. work force is projected to expand by 12.3%; minorities will account for more than 40% of these new participants in the labor force (Fullerton, 1999). Such jobs will require workers who are capable of processing information quickly, critical thinking, problem solving, and teamwork. Unfortunately, many educators and parents—often unknowingly—act in such a way as to perpetuate the common myth that math and science are subjects for white males only. Females and minority students often experience active discouragement, few role models, and less access to advanced coursework as obstacles to choosing a career in science, technology, or engineering (Catsambis, 1995).

As more schools are held accountable, will we see science instruction relegated to a regurgitation of facts (“drill and kill”), with the “hands-on” style of inquiry-based instruction confined to gifted students only? Unfortunately, such a scenario is not impossible, given the prevalent attitude among some educational leaders that not all children need to be systematically exposed to scientific content and methods from the earliest grades.

Socioeconomic status (SES) is an educational issue only slightly less significant than minority status. In our country, the fact that family wealth (or lack thereof) is invariably the single best predictor of demonstrated academic achievement has been repeatedly documented. But those exceptional children who occasionally

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break through the constraints that poverty typically places on academic achievement prove conclusively that SES does not determine potential. Education can be a great equalizer. Thus, we should demand high achievement of all our students, regardless of their background. Setting high expectations in science education in the elementary grades, leading to increasingly improved achievement for both poor and minority students, is being demonstrated convincingly by the St. Louis City Public Schools.

Case Study: St. Louis Public Schools

St. Louis Public Schools (SLPS) is the largest school district in Missouri. It has about 41,000 students in 112 schools, 68 of which are elementary schools. About 81% of students in SLPS are African American; 82% of its student population qualify for free or reduced lunch status. SLPS students have demonstrated gains in elementary school science on the standardized test that the state of Missouri has administered statewide since 1998. This test, the Missouri Assessment Program (MAP), is given annually to each student in Grade 3 in every public school in the state. Table 1 (below) demonstrates the improvements made since 1998 by Grade 3 students in SLPS compared with the Missouri statewide totals.

Key facts to note in Table 1 (next page) are that since 1998, SLPS students improved in the following areas:

- 1) bottom two achievement categories (i.e., Combined Step 1 & Progressing) at an average annual rate of 6%, a rate 600% greater than the 1% average annual improvement rate achieved by all Grade 3 students statewide;
- 2) top two achievement categories (i.e., Combined Advanced & Proficient) at an average annual rate of 5%, a rate more than 200% greater than the 2% average annual improvement rate achieved by all Grade 3 students statewide; and
- 3) composite MAP Index Score by an average 8 points per year, a rate more than 200% greater than the 3 point average annual improvement rate achieved by all Grade 3 students statewide.

Although there is still a gap between the state average in Grade 3 science and the average of students in SLPS, the gap is smaller than ever and narrowing rapidly.

Figure 1 (page 19) provides additional evidence that the achievement gap associated with students' race/ethnicity is being closed gradually by SLPS. Figure 1 for Grade 3 Science shows the composite MAP Index Score by year for black students and for white students within SLPS compared with black students and white students in the rest of Missouri (excluding students from SLPS). The Department of Elementary and Secondary Education (DESE) provided these MAP results disaggregated by race/ethnicity on their web page, but only for the four most recent years since 1999. The

Table 1

Missouri Assessment Program (MAP) Results* in Grade 3 Science from 1998-2002

Comparing Achievement by Year of the St. Louis Public Schools to the Statewide Mean for Missouri

Percent of Students Scoring in Each of Five Levels of Achievement, and the MAP Index Score***

Achievement Level	St. Louis City Public Schools						Missouri					
	1998	1999	2000	2001	2002	Annual Rate of Change** from 1998 to 2002	1998	1999	2000	2001	2002	Annual Rate of Change** from 1998 to 2002
Step 1	27.4	21.1	18.8	17.9	12.3	-4	6.3	5.5	5.2	4.7	3.8	-1
Progressing	27.1	28.8	25.1	22	18.2	-2	14.9	16	13.3	13	11.7	-1
Nearing Proficient	31.7	37.1	33.5	34.8	37.1	1	40.1	43.8	36.6	36.7	36.8	-1
Proficient	12.5	12.1	18.4	20.7	26.2	3	33.1	31	35	35.2	38.7	1
Advanced	1.4	0.9	4.1	4.6	6	1	5.7	3.7	9.9	10.4	9	1
Combined Step 1 & Progressing	54.5	49.9	43.9	39.9	30.6	-6	21.2	21.5	18.5	17.7	15.5	-1
Combined Advanced & Proficient	13.8	13	22.5	25.3	32.3	5	38.7	34.7	44.9	45.6	47.7	2
MAP Index Score***	166.7	171.5	182	186	197.7	8	208.5	205.7	215.5	216.8	218.7	3

* Note: MAP results reported by the Missouri Dept. of Elementary and Secondary Education (DESE), and found on their web site

** Note: Annual Rate of change from 1998 to 2002 calculated by formula ((% 2002 - % 1998)/4)

*** Note: MAP index calculated by DESE formula: (% Step 1 * 1) + (% Progressing * 1.5) + (% Nearing Proficient * 2) + (% Proficient * 2.5) + (% Advanced * 3)

composite MAP Index Score takes into account all five levels of achievement, as shown in the formula contained in a footnote to Table 1.

It is possible to quantify the apparent convergence of achievement scores evident on Figure 1 by calculating the rate of change of the MAP Index Score annually since 1999. In the three years subsequent to 1999, the MAP Index Score has improved annually at different average rates of change for the four groups represented on Figure 1. Black third graders in SLPS averaged the highest rate of change, 9.6 score units per year. Following them were the black students in the rest of the state who changed by an average of 6.2 score units annually. Next were white third grade students from SLPS who averaged 4.8 units of change annually, while white students from the rest of Missouri improved on average by 4.0 score units per year on MAP science in the third grade.

The degree of recent improvement in science test scores at the elementary

level in SLPS schools has been dramatic, particularly during the last school year of 2001-2002. In fact, about two thirds of all SLPS elementary schools improved in science compared with the year before. This means that science improved most of all last year (2002) compared with any of the other three tested subjects of mathematics, communication arts, and social studies at the elementary level. Additionally, a separate analysis showed that, in science, black elementary students in



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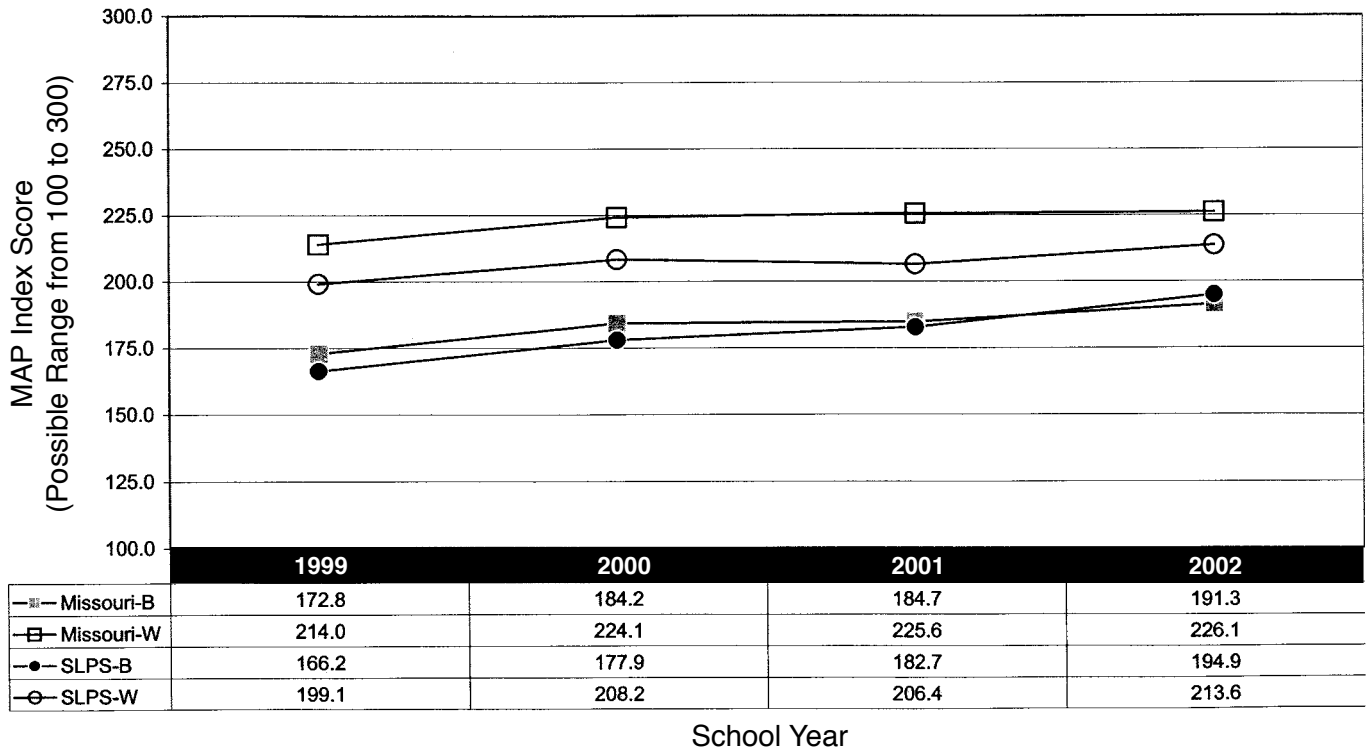
the SLPS are doing on average as well as or better than their counterparts who volunteer to be bused to more affluent schools in 15 largely white public school districts within the adjoining St. Louis County.

Understanding the Data

During her interviews with key stakeholders in SLPS, the first author identified several key factors important to the improvement process. These factors are as follows:

- District administrators provided leadership to bring about change.
- New instructional materials that not only met the needs of the district but also fit well with state and national standards were selected.
- Extensive professional development was provided by the textbook authors to acquaint teachers with the new materials and to familiarize them with newer models

Figure 1: Results of the State Test (MAP) for Science in Grade 3;
 MAP Index Score of Students in SLPS vs. Missouri (Excluding SLPS)
 By Year, and by Race of Student (B=Black; W=White)



of instruction and learning, such as inquiry and discovery.

- Multiple stakeholders were brought together during each phase of planning and implementing the new instructional materials and curriculum.
- The curriculum was segmented, prioritized, timed, and sequenced into content units by teachers and administrators, so that each school would be teaching from the same unit at the same time.
- Regular evaluation and feedback was obtained to guide subsequent training and classroom support. The following section will elaborate on several of these success factors.

Selection of New Instructional Materials

The new science materials that were adopted during SY 2001-2002 were carefully evaluated and pilot tested during the previous school year (SY 2000-2001). Pilot testing was a process new to the district. Ad hoc selection committees of teachers and administrators had made all prior textbook adoptions, with the final decision based largely or exclusively on formal presentations to the committee by the vendors. The pilot testing designed for this occasion, however, was noteworthy for being both intensive and extensive.

- About half of the district's elementary schools participated in pilot testing.

- The pilot testing was conducted for a period of ten weeks.
- Three to five different vendor packages were evaluated at each participating school, each in a different classroom.
- All supplementary materials were evaluated in addition to the textbooks.
- Vendor support and professional development were evaluated in addition to the textbooks.
- All participants discussed all competing vendors during several general sessions held prior to a final vote by the participants.

Planning for Implementation

All stakeholders were involved in careful implementation planning.

These parties included the publisher, the chief academic officer, the science curriculum supervisor, and the divisions of accounting and transportation. The parties met to set details such as time lines, phased implementation, preparing vouchers, shipment schedules and destinations, handling and warehousing the textbooks and supplies, special planning to accommodate the needs of special education teachers, and planning the initial professional development needed by both teachers and school administrators.

Sustained Professional Development

Professional development was done in the summer before the new instructional materials were to be implemented. Teachers needed to become familiar with the style of instruction featuring hands-on inquiry and experimentation. Many did not know how to use demonstration materials in their classrooms, nor were they completely comfortable with and competent in the use of questioning techniques to guide student discussion and discovery of general principles based on observations. Two one-week training sessions in the summer, plus one make-up session in the early fall, were arranged. About 95% of the district's 1,300 teachers in grades K through 5 attended one of these sessions, for which they received a stipend from the district's systemic reform grant through the National Science Foundation.

In order to sustain momentum during the school year itself, teachers received additional training sessions designed by local science institutions, such as the Missouri Botanical Garden, the St. Louis Science Center, and the St. Louis Zoo. These and other major

community partners attended the district's summer training sessions in order to become better acquainted with the new teaching materials. This also allowed them to observe the teachers during these sessions in order to identify special needs to be addressed through subsequent professional development. Furthermore, all such organizations were instructed to ensure that all future proposals for training of the district staff must conform to the district's new content standards and instructional materials.

Involving All Stakeholders

The district's reading specialists were also included as part of the science implementation team. In fact, the connections between science and reading literacy were made explicit during a portion of the district's summer professional development training sessions. Science content questions now form portions of the district's quizzes in communication arts, and school administrators use science materials as the base texts for practice sessions in reading and writing. According to Principal Mamie Womack of Froebel Elementary School, "Reading is not just reading in the basal reading text. It is reading in the content areas and giving a grade in reading while covering content areas."

Froebel Elementary School is typical of the type of school in St. Louis that has recently begun to embrace new standards-based, inquiry-mode instruction, and which has started to make significant gains in student achievement as a consequence. Froebel is a large, non-magnet school with rates of minority enrollment and family poverty significantly above the district's average. Yet the recent improvement in Froebel's test scores

is evidence that change is taking place. Last year, Froebel improved on all four subjects of the MAP, and in both indicators for each subject. The school improved most of all in science. This overall improvement was possible only through the dedication to reform and improvement of Froebel's principal, Ms. Womack, who is starting just her third year at the school.

Principal Womack has made science a priority at the school, where teachers include science in their morning block

Having a common schedule of instructional topics across the district's schools helps to ensure that students who move do not experience any discontinuity of content from one school to the next.

of literacy practice. Teachers use a variety of instructional strategies to engage the students and to hold their attention, including the use of science content readers, read-aloud big books, having students read along while listening to text on audio CD, and doing shared reading. Instruction relevant to science content is presented during afternoon activities that are primarily of the "hands-on" variety. Subsequently, students devote time to writing descriptions of the experiment and to building their vocabulary by explicating the science words used in the demonstration or experiment. The teachers also have students

practice writing stories that include the new science words and content. In addition, one Friday per month is designated as “Science Friday” and dedicated to science. The whole school participates in Science Friday, during which students demonstrate hands-on activities and share what they have learned in their own classroom with students in other classrooms.

Finally, the “buy-in” of principals to the new curriculum, the new textbooks, and the new methods of instruction in science was crucial to the success of the implementation process. Principals, even in schools not involved in pilot testing, clearly noticed or heard about the excitement generated by the pilot-testing process. In part because of this, the principals proved to be a receptive and supportive audience at their orientation workshop held just prior to the start of the school year.

Developing Paced Modules of Instructional Content

Thirty to forty percent of the district’s students typically change schools during any given year. Having a common schedule of instructional topics across the district’s schools helps to ensure that students who move do not experience any discontinuity of content from one school to the next. Keeping teachers on-track within this instructional framework is primarily the responsibility of school-based instructional coordinators and school principals. The district’s Curriculum Supervisor, Loretha Allen, the district’s Curriculum and Professional Development Coordinator, Robin Kyles, and the Title 1 Supervisor, Mary Schroeder provide assistance and oversight. One of their jobs is to make sure that teachers and school administrators have, understand, and use the printed guide to the district’s

science curriculum, the schedule of instruction (pacing chart), and the district’s “home grown” periodic assessments. By moving the physical science module to the beginning of the school year, for example, they helped to ensure that this topic, so often neglected or omitted, was actually taught. Changing the order of instruction may help to explain why the students improved so much in the MAP content standards of matter and energy, and force and motion.

Periodic Review and Feedback

A full-time internal evaluator now covers the divisions of math and science. This position provides these two divisions with quick access to, and analysis of, results of national (TerraNova), state (MAP), and local (district “quizzes”) results shortly after they become available. Getting time-critical information in a timely fashion makes it possible for curriculum supervisors and coordinators to identify problem areas and schools in need so that effective intervention can be swiftly applied. Schools continue to contribute to the feedback process by sending their key teachers (“lead” teacher for science) to periodic meetings held by the district’s curriculum specialists. These meetings

Success in teaching science in the elementary schools of SLPS has taken a great deal of collaboration among support staff, teachers, and school administrators.

serve to inform the schools about current status, as well as to inform district-level staff of any strategies that are not working as intended or planned.

Success in teaching science in the elementary schools of SLPS has taken a great deal of collaboration among support staff, teachers, and school administrators. Now teachers are guiding and assisting each other, both within schools on a daily basis, as well as through grade-specific formal training that is offered monthly by a cadre of trained teachers to their fellow teachers in the district. These training workshops also include multi-grade sessions designed just for special education teachers. Providing such science enrichment activities to teachers on a periodic, routine basis is proving to be a vital link in improving the quality of science teaching. The hope is that success will breed success. That is, teachers become enthusiasts for science as they begin to recognize the increased mastery of science on the part of their students.

Conclusion

Bat Masterson, one-time sheriff of Dodge City and a friend of Wyatt Earp, spent the last twenty years of his life as a sports writer in New York City. In one of his articles he concluded: “Everybody in life gets the same amount of ice except that the rich get it in the summer while the poor [get it] in the winter.” (Montini, 1998). Elementary school science education is in danger of becoming like ice in the summer, a treat only for students who are already high achievers, but not something for the masses of average or underachieving students. Through the efforts of many dedicated people, the Public School District in St. Louis is beginning to show that it is possible

for an entire district to achieve success in science, and that it is not just an isolated effect confined to a few privileged schools. It is their hope, and their intention, to continue to progress toward higher science achievement in the future—achievement of ALL students.

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Providing Effective Professional Development: Lessons From the Eisenhower Program

Results are presented that show specific management and implementation strategies, such as aligning standards and assessments with professional development activities, continuous improvement efforts, and coordination with other funding sources, lead to higher quality professional development, as characterized by six identified features of professional development.

Our country's current education reforms seek to foster high standards for teaching and learning for all children. Such standards are intended to create a fundamental shift in what students learn and how they are taught (National Educational Goals Panel, 1995; Porter, Archibald, & Tyree, 1991; Porter, Smithson, & Osthoff, 1994). The success of such ambitious education reforms hinges, in large part, on the qualifications of teachers. Student learning will be transformed only if high standards are reflected in teachers' classroom practice (Loucks-Horsley, Hewson, Love, & Stiles, 1998; National Commission on Teaching & America's Future, 1996). Not surprisingly, teachers' professional development has been the single largest investment of most reform initiatives. Unfortunately, much of this investment supports ineffective practices (Cohen, 1990; Cohen, McLaughlin, & Talbert, 1993; Elmore, Peterson, & McCarthy, 1996; Little, 1993; Richardson, 1994; Stiles, Loucks-Horsley, & Hewson, 1996).

The work described here identifies specific characteristics that make in-service professional development effective, and the strategies school districts can use to provide such effective professional development. Findings are based on national probability samples of teachers and professional development providers, and a purposeful longitudinal sample of teachers.

Results come from a coordinated set of studies designed to evaluate the effectiveness of the federal government's Eisenhower Professional Development Program (Birman et al., 2000; Garet et al., 2001; Desimone, Porter, Garet, Yoon & Birman, in press; Desimone, Porter, Birman, Garet & Yoon, in press). The Eisenhower Professional Development Program, established in 1984 and reauthorized in 1988 and 1994 as Title II of the Elementary and Secondary Education Act (ESEA), is the federal government's largest investment solely focused on developing the knowledge and skills of classroom teachers. The Eisenhower program aims to support high-quality

professional development primarily in mathematics and science. Part B of the Eisenhower program, with a 1999 appropriation of about \$335 million, provides funds through state education agencies (SEAs) to school districts, and through state agencies for higher education (SAHEs) to institutions of higher education (IHEs) and nonprofit organizations.

The study of Eisenhower professional development reported here contributes to our general knowledge about effective professional development activities and policies for promoting them for several reasons. First, our sample is generalizable to 93% of U.S. school districts, since at the time of the study, only 7% of districts did not receive Eisenhower funding. Second, the Eisenhower program is a source of funding for professional development activities, not a specific approach to professional development. The program funds a wide range of activities, including workshops and conferences, study groups, professional networks and collaboratives,

task forces, and peer coaching. Third, activities supported by Eisenhower are often co-funded with other sources—Eisenhower-assisted activities also may receive funding from states, school districts, and other federal programs. Therefore the information in this study about the quality and effects of Eisenhower-assisted activities also applies to professional development funded through other sources, at least in mathematics and science.

Data

During the 1997-98 school year, we conducted telephone interviews with a national probability sample of Eisenhower coordinators in 363 school districts.¹ We also collected data from a mail survey of a national probability sample of 1,027 teachers who participated in 657 Eisenhower-assisted activities.^{2,3} To complement these findings from our national, cross-section sample of teachers, we surveyed 287 mathematics and science teachers in 30 schools, at three points in time—the fall of 1997, the spring of 1998, and the spring of 1999.⁴

The multiple sources of data are designed to provide an accurate description of program-funded activities, analyses of the features of these activities, and their effects on teacher practice. Our national and longitudinal data have a number of strengths. First, our descriptions of the nature and quality of professional development provided through the Eisenhower program are based on national probability samples, which increases the representativeness and generalizability of the findings; and each sample had an excellent response rate.⁵ Second, our longitudinal data provide direct estimates of changes in teaching practice over time. We

use the more rigorous longitudinal data to test whether the results identifying the characteristics of effective professional development based on cross-sectional data can be replicated. Finally, we have taken a number of steps to maximize the validity and reliability of the national survey data. For example, although the telephone interview and teacher survey data are based on self-report, most of the data represent an accounting of behaviors, not direct judgments of quality that might be more likely to be biased in a positive direction. And the measures we use are composites, which have been shown to have greater reliability and validity than single indicators (Mayer, 1999). In addition, the substantial variation in responses teachers and district administrators provided to these behavioral items, as well as the consistency in teacher and district administrator responses, tends to bolster our confidence in the validity of the data.

Our data do, of course, have limitations. First, we used only one district informant in our district data set. Other informants might have responded differently (e.g., Spillane, 1998), affecting the reliability but not the validity of our variables. Second, our dependent variables are teacher reports of change and district reports of features of professional development; we do not have direct measures of gains in student achievement. Third, our survey results lack in depth what case-study research lacks in generalizability; the variables in our analyses were identified a priori based on previous research. Both the strengths and limitations of our data sets should be kept in mind in the interpretation of the results.

In this article, we first describe how we identified the key features of effective, high-quality professional development, and present results from our national probability sample of teachers about the extent to which these features relate to teachers' reports of changes in teacher knowledge, skills, and practice. Second, we report the results of our longitudinal study showing the characteristics of professional development that change teaching practice, and discuss how these compare to results from our national probability sample of teachers. Third, we use results from the national probability sample of teachers to describe the extent to which Eisenhower-assisted activities have the high-quality features associated with changes in practice. Fourth, we use our data from district Eisenhower coordinators to examine district policies and procedures that are associated with providing high-quality professional development, and the extent to which districts engage in these practices. Finally, we conclude by highlighting policy implications for schools and districts for designing effective professional development for teachers.

What Are the Key Quality Features of Professional Development?

Over the past decade, a considerable literature has emerged on professional development, teacher learning, and teacher change (Corcoran, 1995; Hargreaves & Fullan, 1992; Lieberman, 1996; Little, 1993; Loucks-Horsley et al., 1998; Richardson, 1994; Sparks & Loucks-Horsley, 1989; Stiles et al., 1996). The research literature contains a mix of large- and small-scale studies, including intensive case studies of classroom teaching, evaluations



Despite the size of the literature, relatively little systematic research has been conducted on the effects of professional development on improvements in teaching or on student outcomes.

of programs designed to improve teaching and learning, and surveys of teachers about their preservice and in-service professional development experiences. In addition, there is a large literature describing “best practices” in professional development, drawing on expert experiences. Despite the size of the literature, relatively little systematic research has been conducted on the effects of professional development on improvements in teaching or on student outcomes. Also, there is very little research on the relative effects of *alternative forms* of professional development. The research that exists, however, along with the experiences of expert practitioners, does provide some preliminary guidance about the characteristics of high-quality professional development (see Loucks-Horsley et al., 1998).

In particular, several recent studies suggest that professional development that focuses on specific mathematics and science content, and the ways students learn such content, is especially helpful (Cohen & Hill, 2000; Kennedy, 1998).

Based on the available research and the ideas in the literature on “best practices,” we created a set of measures describing six key features of professional development. Although there are other potentially important features of professional development, the set we chose is well grounded in the literature.

Our analysis of the characteristics of high-quality professional development first focuses on “structural features”: (a) the form or organization of the activity—that is, whether the activity is organized as a reform type, such as a study group, teacher network, mentoring relationship, committee or task force, internship, individual research project, or teacher research center, in contrast to a traditional workshop or conference; (b) the duration of the activity, including the total number of contact hours that participants spend in the activity, as well as the span of time over which the activity takes place; and (c) the degree to which the activity emphasizes the collective participation of groups of teachers from the same school, department, or grade level, as opposed to the participation of individual teachers from many schools.

In addition to these structural features, we focus on three dimensions of the substance or core of the professional development experience. We examine three “core features”: (a) the content focus of the activity—that is, the degree to which the activity is focused on improving and deepening teachers’ content knowledge in mathematics or science; (b) the extent to which the activity offers opportunities for active learning—that is, opportunities for teachers to become actively engaged in the meaningful analysis of teaching and learning, for

example, by reviewing student work or obtaining feedback on their teaching; and (c) the degree to which the activity promotes coherence between teachers’ professional development and other experiences, for example, by encouraging the continued professional communication among teachers and by incorporating experiences that are consistent with teachers’ goals and aligned with state and district standards and assessments.

How Do Each of the Six Quality Features Relate to Teacher Outcomes?

The literature suggests that all six of these features—the three structural and three core features—would influence the effectiveness of professional development in changing teacher practice. We used our survey of teachers who participated in Eisenhower-assisted professional development to estimate the strength of the relationships among features of professional development and teacher outcomes—enhanced knowledge and skills and changed teaching practice. We developed a formal model to represent the relationships and to test the view that structural features of professional development play an important role in determining the substance or core of the professional development experienced by teachers; and that the core features of the professional development experience contribute to teacher outcomes, including enhanced knowledge and skills and improvements in teaching practice.⁶

Although we suggest a logic of events here (and similarly in our presentation of results from the district data), it should be emphasized that components of the system are likely

interactive and may occur simultaneously. These national data are not longitudinal, so we cannot test the causal ordering. We can, however, identify the strength of relationships among variables. We suggest a logic of events to help explain how features of professional development might affect changes in classroom practice, but our model should not be considered to exclude the possibility of nonrecursive effects or an alternative temporal ordering.

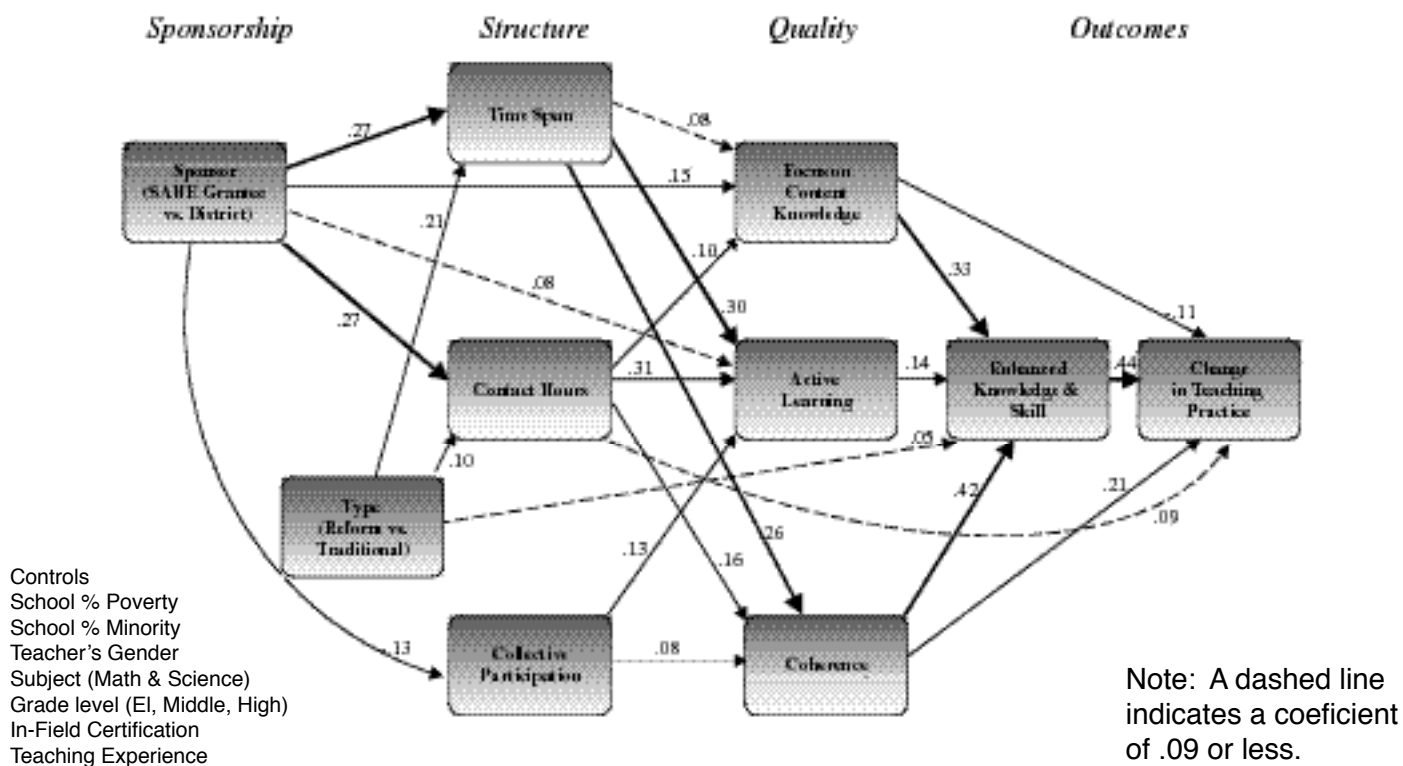
We estimated the size of the relationships with ordinary least squares (OLS) regression, a statistical approach that allows us to measure the relationships among features of professional development while

separating out the effects of the other factors. In our recursive system of simultaneous equations, using separate OLS estimates for each equation is equivalent to full system maximum likelihood (e.g., Greene, 1993) and is a commonly accepted method of path modeling (Bohrnstedt & Knoke, 1982; Li, 1975; Pedhazur, 1982). That is, the variables are ordered from left to right, and variables on the right depend only on variables to their left. We included the full set of control variables in each equation.⁷

We found that all three core features—content focus, active learning, and coherence—have a positive association with enhanced knowledge and skill, which in turn

affects changes in teaching practices, as reported by the teachers in our sample.⁸ Figure 1 depicts these relationships. (See Table A.1 in the Appendix for the regression coefficients that support Figure 1.) Both content focus and coherence have substantial positive associations with enhanced knowledge and skills, indicating that activities that give greater emphasis to content and that are better connected to teachers' experiences and reform efforts are more likely to produce enhanced knowledge and skills. Professional development that provides opportunities for active learning for teachers is also related to enhanced knowledge and skills, but the relationship is less strong.

Figure 1
The Relationships of Features of Professional Development to Teacher Outcomes



Both content focus and coherence have substantial positive associations with enhanced knowledge and skills, indicating that activities that give greater emphasis to content and that are better connected to teachers' experiences and reform efforts are more likely to produce enhanced knowledge and skills.

Teachers who report enhanced knowledge and skills also are likely to report changing their teaching practices. Further, independent of this relationship between knowledge and skills and teaching practice, the coherence of professional development activities has an important positive relationship to change in teaching practice. This suggests that teachers are more likely to change their practice if their professional development is connected to their other professional development experiences, is aligned with standards and assessments, and fosters professional communication. These features of professional development relate to changes in practice even among teachers who have gained the same underlying knowledge and skills through their other professional development experiences.

As suggested in the literature on professional development, reform

types of activities tend to produce more positive reported outcomes than traditional types, but our results indicate that this relationship is largely indirect. That is, *reform activities tend to produce better outcomes primarily because they tend to be of longer duration*. Traditional and reform activities of the same duration tend to have the same association with reported outcomes. The results also show that activities of longer duration and activities that encourage collective participation of teachers in the same school or grade tend to place more emphasis on content, provide more opportunities for active learning, and provide more coherent professional development than other activities. These features in turn promote positive teacher outcomes, as we discussed earlier.

How Does Professional Development Change Teaching Practice Over Time?

Mathematics and science teachers in our longitudinal study reported on their classroom practices in Year 1 (1997), characteristics of their professional development in Year 2 (1998), and then again their classroom practices in Year 3 (1999). With these three years of data we were able to look at changes in teaching practice over time and analyze the effect that participation in a professional development activity had on those changes. Teachers reported on only one professional development activity, so our measure is conservative. A more complete accounting of professional development experiences, had that been feasible, would likely have produced stronger relationships between professional development characteristics and changes in teaching practice.

We focused on three areas of teaching practice that are considered desirable by researchers and school reformers, and for which we had exactly parallel measures of professional development. The three areas are (1) use of technology, such as calculators and computers, to develop models or collect data (Cognition and Technology Group at Vanderbilt University, 1994; Means, 1994; Means et al., 1993; Means & Olsen, 1995; Sivin-Kachala & Bialo, 1996), (2) higher order instruction, such as work on problems with no obvious solution and debating ideas and explaining reasoning (Raizen, 1998; NCTM, 1998; NRC, 1996), and (3) use of alternative assessments, such as performance tasks, reports, projects, and essays (Koretz, Stecher, Klein, & McCaffrey, 1994; Mitchell, 1996).

In addition to asking teachers to describe the extent to which their professional development focused on these strategies, we asked teachers to describe the features of their professional development activity. We used the same measures we used in the national teacher survey—reform type, collective participation, duration, active learning, and coherence. The sixth feature, content, was defined by the emphasis of the strategy, i.e., technology use, higher order instruction, and use of alternative assessments.

Estimating the effects of professional development using a hierarchical linear model, we found that teachers who participated in professional development in Year 2 that focused on a particular strategy in technology use, use of higher order instruction, or use of alternative assessments were significantly more likely to increase their use of these strategies in Year 3. (Results showing the effect of pro-

professional development on changes in teaching practice in technology are presented in Table A.2; the results for instruction and assessment, and a more detailed explanation of our methods, can be found in Desimone et al., in press.) More important, we found

that, consistent with results from our national probability sample, features of high quality (e.g., contact hours, collective participation) increased the effect of the professional development. Table 1 shows the effect that quality features had on the magnitude of the

change in teachers' practice due to participation in professional development. All of these relationships are in the hypothesized direction, but some are not significant, perhaps due to the small sample size.

TABLE 1
Relationship Between Features of Professional Development and Activities Focused on Specific Teaching Practices (Sign and Significance of Relationships)¹

Independent Variable: Features of Quality of Professional Development	Technology		Instruction		Assessment	
	Effect of Specific Strategy ^a β_{21} (relative focus)	Effect of Set of Related Strategies ^b β_{06} (mean focus)	Effect of Specific Strategy β_{21} (relative focus)	Effect of Set of Related Strategies β_{06} (mean focus)	Effect of Specific Strategy β_{21} (relative focus)	Effect of Set of Related Strategies β_{06} (mean focus)
Reform type	-.049	.170	.018	.872**	-.225	.932*
Time span	.042	.039	.035	.065	-.014	.095
Contact hours	.000	-.004	.002	.004	-.001	.008
Collective participation	.326*	.027	.011	.193	-.183	.313
Active learning	.041+	.019	.001	.057+	-.023	.042
Coherence	.047	.045	.011	.086	.046	.141+

^a This indicates the effect of professional development if it focused on only one practice in a particular area.

^b This indicates the effect of professional development if it focused on all the practices in a particular area.

^c Gray shading indicates that the effects are statistically significant.

+ p<.10, * p<.05, **p<.01

How to read this exhibit: The “-“ in the first row in the first column on the left shows that participating in a professional development activity that is a reform-type activity decreases the effect of professional development focused on technology use, but this relationship is not statistically significant. The “*“ in the fourth row in the first column on the left shows that participating in a professional development activity that has collective participation increases the effect of professional development focused on technology use, and this relationship is statistically significant (indicated by the gray shading).

¹ “Content focus” is not included in the list of features of quality because the measure of whether the activity focused on a particular teaching practice is a proxy measure for content focus.

How Common Are the Six Features of Quality?

Our national and longitudinal teacher data describe how the six features of professional development are related to one another and to teacher outcomes. This leads us to ask how prevalent these features are in professional development activities. Our national probability sample of teachers who have participated in Eisenhower-funded professional development activities provides a national picture of professional development. In this section we describe the characteristics of the Eisenhower district professional development in which teachers in our national sample participated.

Between 75% and 80% of teachers participate in district activities that are traditional in form, such as workshops, courses, or conferences; relatively few activities are reform types of activities, such as study groups, networks, or mentoring relationships. Further, while the average number of contact hours of district activities (25 hours) has approximately doubled since the last evaluation of the Eisenhower Professional Development Program, conducted in 1988-89, the median number of hours for district activities is only 15 hours.⁹ Only 20% of district activities span at least six months. But our data also show that there is a great amount of variability in the time span of district activities. Finally, relatively few district activities emphasize the collective participation of teachers from the same department, grade level, or school; 20% of teachers in district Eisenhower-assisted activities report participating with other teachers in their department or grade level.

Fifty-one percent (51%) of teachers in district activities participate in activities that place a major emphasis

on mathematics or science content. Relatively few teachers report a major emphasis on each of 18 separate indicators of active learning. For example, only 5% of teachers in district activities report that their teaching was observed by the activity leader. However, professional development does tend to have elements that promote coherence with other aspects of teachers' professional experiences. For example, more than three quarters of teachers in district activities report that their activities are aligned with state and district standards; between 30% and 40% of teachers report that their activities build on prior professional development; and 50-70% say the activities are followed up with later activities.

Our data show that few features of high quality are prevalent in professional development activities. However, given the enormous variability in the quality of professional development activities, our data show that some districts are providing high-quality professional development. For example, although many district activities are short, 2% of teachers in district activities are in activities spanning more than one year, and 18% are in activities lasting 6-12 months. That some districts provide activities of extended duration, with collective participation, a major focus on content knowledge, a major emphasis on active learning, and coherence with teachers' other experiences, represents an "existence proof" that it is possible for districts to provide such activities.

The reason many districts generally do not provide high-quality professional development may be the cost. High-quality professional development is expensive, and we estimate that districts spend only \$185 per teacher

participation.¹⁰ Districts may spend so little money per teacher because they feel a responsibility to provide professional development to all of their teachers. This may push them in the direction of professional development with lower costs per participation.

How Do District Policies and Practices Relate to the Quality of Professional Development That They Provide?

The quality of professional development activities also may be a function of how districts operate and manage these activities. Our national probability samples of district Eisenhower coordinators provide data to describe how districts operate and manage their professional development activities, and how this relates to their quality.

Characteristics and Effects of District Policies and Practices

Each district receiving Eisenhower funds generally uses the funds to support a collection of professional development activities. The collection of professional development activities that a district supports can be viewed in its entirety as its "portfolio" of Eisenhower-assisted professional development activities. In our analysis, we examine the factors that influence the quality of district portfolios of professional development activities.

School districts play a critical role in setting the context for professional development activities (Elmore, 1993; Knapp et al., 1991; Spillane, 1996; Spillane & Jennings, 1997; Spillane & Thompson, 1997). Districts can set a vision or focus for professional development by aligning professional development activities with standards, assessments, and other reform efforts

in the district (Cohen & Spillane, 1992; Elmore & Burney, 1996; Spillane, 1996; Webb, 1998). This increases program coherence (Smith & O'Day, 1991; Cohen & Hill, 2000), which in turn can increase teacher motivation and encourage changes in instruction (Fullan, 1996; Spillane & Jennings, 1997). Districts can also establish a vision by their use of funds. Leveraging resources can affect the quality of professional development that districts offer (Corcoran, 1995); and co-funding activities can indicate that districts have a coherent focus for their professional development program (Elmore & Burney, 1996; Guskey, 1997).

Teacher involvement in planning for professional development is another district strategy associated with more effective professional development (Clark, 1992; Loucks-Horsley et al., 1998). In addition, district strategies of continuous improvement have been shown to help target local priorities and increase the quality of professional development. Such strategies include establishing evaluation and accountability mechanisms (O'Day, Goertz, & Floden, 1995) and using indicators to shape priorities and evaluate activities (Fuhrman, Clune, & Elmore, 1988; Guskey, 1997; Loucks-Horsley et al., 1998).

In assessing district policies and practices, we focus on the role of the following key management mechanisms, discussed in the literature and required in the Eisenhower legislation: (1) the *coordination (co-funding)* of activities with other

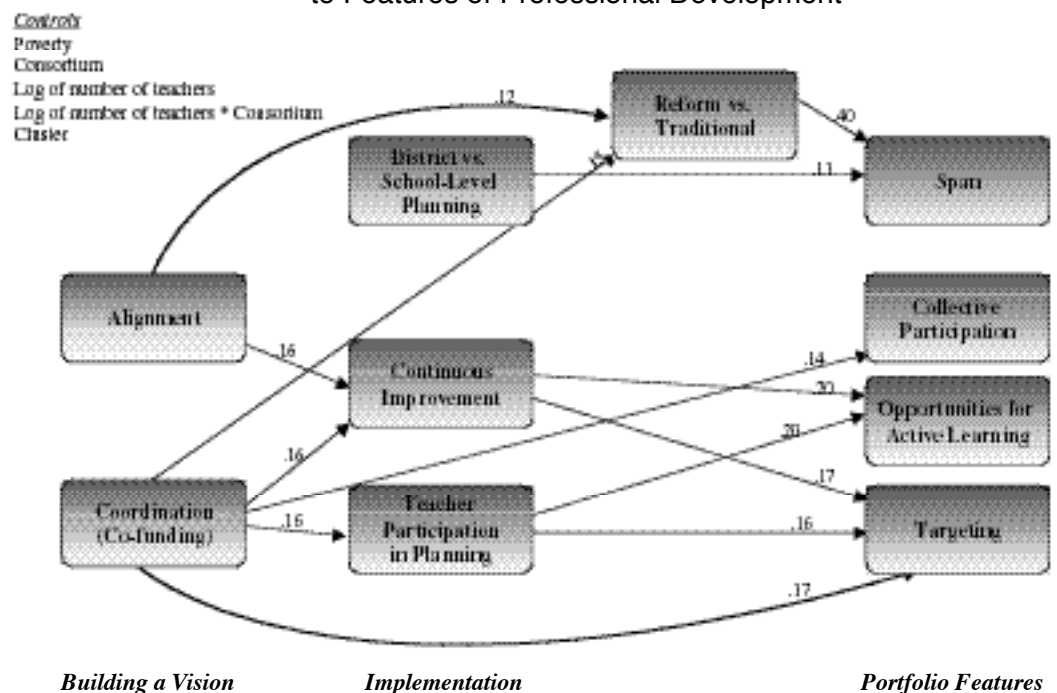
sources of funding for professional development; (2) the *alignment* of activities with state and district standards and assessments; (3) the *participation of teachers* and school-level staff in planning professional development activities; and (4) the use of a process of *continuous improvement*, including monitoring progress against measurable objectives and performance indicators.

The measures we used to characterize the quality of a district's portfolio of Eisenhower-assisted professional development were similar to those we used to measure the quality of individual activities on the teacher survey: (1) the percent of the districts' participation in *reform types* of activities, (2) the average *span* of time of activities (i.e., number of days, weeks, or months), (3) the number of opportunities for *active learning* in in-district workshops

and institutes, and (4) the degree of *collective participation* in in-district workshops and institutes. As described earlier, the data from our national sample of teachers show that each of these dimensions is related, either indirectly or directly, to improvements in teachers' knowledge and skills and changes in teaching practice. Thus, we consider each of these dimensions as an indicator of high-quality professional development.

As with our analysis of the national teacher data, we developed a model of the relationships among district management strategies and the quality of activities, shown in Figure 2 (see Table A.3 in the Appendix for corresponding regression coefficients.) Using data from our national district Eisenhower coordinator surveys, we estimated the size of the relationships among the variables in our model. We found that districts are more likely to have higher

Figure 2
Relationship of District Management
to Features of Professional Development



quality professional development activities when they: (1) use multiple funding sources to co-fund professional development activities; (2) align activities with state or district standards and assessments; (3) monitor activities and their effects using continuous improvement efforts; and (4) plan at the district level and involve teachers in planning.

Specifically, districts that engage in more co-funding of Eisenhower activities with other programs tend to support more reform types of activities than districts that engage in less co-funding, and they tend to support professional development with more opportunities for collective participation. In addition, districts that engage in more co-funding tend to engage in more extensive continuous improvement efforts and they tend to involve teachers more widely in planning, both of which are related to increased opportunities for active learning. Finally, districts that align professional development with standards and assessments are more likely to offer reform types of professional development activities and to engage in continuous improvement efforts, which are related to increased opportunities for active learning.

Districts vary in their adoption of these management strategies that lead to high-quality professional development. Most districts report co-funding professional development with other sources of funding, aligning activities with standards and assessments, and including teachers in planning, but few engage in a process of continuous improvement, such as developing and using performance indicators (see Desimone, Porter, et al., in press, for complete data on these descriptive statistics). Specifically, for example, on average districts co-fund

with 2 out of 10 major Department of Education programs (more districts co-fund with the National Science Foundation—for example, 86% co-fund with NSF's Urban Systemic Initiative); reports of alignment range from 85% of districts reporting that their professional development activities are aligned with state and district standards, to 69% of districts reporting that professional development is aligned with district assessments; 65% of teachers are in districts in which teachers participate in formal committees at the district level, and 62% of teachers are in districts in which teachers participate in formal committees at the school level; and fewer than one in five, or about 18%, of teachers are in districts that currently collect data on performance indicators that they have established to guide their professional development efforts. Similarly, less than 25% of the nation's teachers are in districts that report being affected by their states' indicators for professional development.

Further, we found significant and systemic differences in how large districts manage their professional development activities. Compared to small districts, large districts are generally more likely to manage their portfolios better and to provide higher quality professional development. Specifically, larger districts are more likely to align their professional development with standards and assessments, to co-fund their professional development activities, and to engage in more continuous improvement efforts; large districts also provide professional development activities of longer duration, with more opportunities for collective participation and active learning.¹¹

Large districts may outperform smaller districts because they have a better infrastructure and more capacity (e.g., large districts more often have curriculum specialists), which may enable them to provide higher quality professional development. Large districts also may have a greater variety of funding sources in addition to Eisenhower. This could create a larger pool of funding for professional development and encourage large districts to provide higher quality professional development, which costs more. Finally, large districts may face complexity that demands more efforts to monitor professional development activities.

Implications for Professional Development Funders and Providers

These findings from our national probability samples and our longitudinal sample have a number of implications for policy. By using national probability samples, our analyses support and extend previous case-study and smaller scale survey work in identifying six key features of effective professional development. Our analysis of longitudinal teacher data over three years supports and validates these findings. Specifically, our research indicates that professional development should focus on deepening teachers' content knowledge and knowledge of how students learn particular content, providing opportunities for active learning, and encouraging coherence in teachers' professional development experiences. Schools and districts should pursue these goals using activities that are of greater *duration* and involve *collective participation*. While *reform* types of professional development are more effective than *traditional* types, the

advantages of reform activities are explained primarily by their greater duration. Our research also identifies the high-quality characteristics that are more prevalent (e.g., coherence) and those that are less common (e.g., opportunities for active learning). Generally, there is much room for improvement.

Our analyses replicate for the first time on a national probability sample the importance of duration and active learning. Our analyses extend earlier work, directing us to rethink these mechanisms through which “reform” activities may be more effective. Specifically, we found that the strength of reform activities is that they tend to have more contact hours and span a longer period of time than traditional activities. In turn, reform activities are more likely to have the core features of high quality—active learning, coherence, and content focus. We also provide evidence for previous speculation that coherence and collective participation are important components of high-quality professional development. And our research is one of several recent works that document the profound importance of content (e.g., Cohen & Hill, 2000; Kennedy, 1998). We found this in both our longitudinal and national cross-sectional samples of teachers. Generic professional development that focuses on teaching techniques without a content focus does not appear to be effective.

Our analyses provide three main insights into managing professional development activities.

First, our analysis of a national probability sample of Eisenhower district professional development coordinators shows that certain management and implementation

strategies are related to the quality of professional development activities that districts provide to teachers. Specifically, alignment with standards and assessments, district co-funding, continuous improvement efforts such as establishing indicators and conducting needs assessments and evaluation, and teacher involvement in district-level planning predict the core and structural features of professional development activities. Thus, our findings provide support for encouraging districts to use these policies and practices toward the provision of higher quality professional development.

Second, district capacity plays a critical role in determining which districts provide high-quality professional development. We speculate that districts could provide high-quality professional development, and we find some examples of districts doing exactly that. What we do not know from our analyses is the percentage of districts that have the capacity to offer such high-quality professional development. Our analyses indicate that larger districts have greater capacity. This greater capacity may be explained, in part, by their larger district staff and, in part, by their greater funds. Future research should explore in more detail the characteristics and conditions that give some districts the capacity to provide high-quality professional development.

Third, our analyses suggest that, in addition to management and implementation and capacity issues, one reason districts may provide lower quality professional development is cost. Not surprisingly, high-quality professional development costs more per participant than lower quality professional development. Districts may

feel a responsibility to reach a large number of teachers, and this is reflected in the cost per participant. The question is, should districts continue to spread money across as many teachers as possible? Or should they focus the money on a small number of teachers, so that they can provide higher quality, more influential professional development? Our results suggest the money should be focused. Districts could increase the quality of the professional development they provide by focusing their money on a small number of teachers, rather than spreading it across a large number of teachers.

These lessons are timely, given the current emphasis of standards-based reform on teachers’ professional development. In this study we have used our national probability and longitudinal data to identify features of effective professional development activities, describe their prevalence, and determine the district management practices that are related to the provision of high-quality activities. Our findings suggest positive directions for schools and districts to increase the quality of the professional development activities that they provide and thus to increase the chances of having a positive effect on teachers and, ultimately, student learning.

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Notes

1. The probability of a district's being chosen for our sample was proportional to district size (i.e., the number of teachers in the district). The sample was also selected to allow variation on poverty level.
2. See Garet et al. (2001) for additional details about the sampling design and methodology.
3. As part of the study we also conducted a series of case studies in 10 school districts (two districts in each of five states). The case studies provide detailed information about how the

Eisenhower Professional Development Program operates in selected states, school districts, and schools; for the most part case study data support and help to explain findings from the survey data.

4. Four hundred thirty (430) teachers responded to the 1996-97 survey; 429 teachers responded to the 1997-98 survey; and 452 teachers responded to the 1998-99 survey. The response rate for the first wave was 75%; for the second wave, it was 74%; and for the final wave in 1998, 75%. Given our analysis strategy of looking for change over time in the same teachers, the sample for the analysis is restricted to teachers who returned all three waves of the survey, who participated in professional development in 1997-98, and who continued to teach the same course over all three waves of the survey. The last restriction is necessary because changes in the course taught might introduce changes in teaching practice apart from the effects of professional development experiences. Finally, the sample is restricted to teachers who provided complete data on all of the necessary items. The number of teachers meeting these conditions ranged from about 125 to 135, depending on the specific analysis. See Desimone, Porter, Garet, Yoon, & Birman (in press) for a more complete description of the sampling, response rates, design, and methodology.
5. The national probability sample for district program coordinators has an 88% response rate. The national probability sample of teachers who participated in Eisenhower professional development activities has a response rate of 72%. The 72% response rate is especially high considering the multistage process necessary to complete the sample. District coordinators had to submit the complete list of professional development activities provided during the prior year and the number of participants. Two activities were selected from each district with

probability in proportion to size, and from those, complete rosters of teachers were collected from which two teachers were randomly selected and surveyed.

6. Since it is possible that teachers in different types of schools or teachers with different characteristics may experience different types of professional development, we included school and teacher characteristics as control variables in our model. The model includes the characteristics of the schools in which the participating teachers teach: the percent of students eligible for free lunch and the percent of minority enrollment. The model also includes five characteristics of the participating teachers: gender, subject of the teacher's professional development experience (mathematics or science); grade level (elementary, middle, or high school); whether the teacher is certified in the teacher's main teaching field; and the teacher's teaching experience, in years. In addition, since we were interested in understanding the differences between activities supported through the district and IHE component of the program, we also included the sponsorship of the activity as a variable in the model (coded 1=IHE, 0=district). Results for these differences are not reported here, but are discussed in Garet et al. (2001).
7. Estimating this model with structural equations (e.g., LISREL) would not enable us to estimate a nonrecursive model, but would allow us to take into account the reliability of the measures (Bollen, 1989; Hanushek & Jackson, 1977).
8. For more detail on these and other results reported in this article, see Birman et al. (2000), Garet, et al. (2001), Desimone, Porter, et al. (in press) and Desimone, Porter, et al. (in press).
9. The 1988-99 evaluation collected data on duration from districts rather than

teachers, so a comparison of results from the 1988-89 and the current evaluation should be interpreted as providing an indication of the general magnitude of the change rather than a precise numerical estimate. See Knapp, Zucker, Adelman, & St. John (1991).

10. A "participation" is a teacher participant in an Eisenhower-assisted activity. Teachers who participate in more than one activity are counted separately for each activity in which they participate. The dollar per participation figure for districts includes federal Eisenhower dollars only and does not include the 33% matching requirement.
11. Throughout our analyses of district data, we tested to see where patterns of Eisenhower support for professional development differ significantly according to the district poverty level or the size of the district. All of our analyses simultaneously control for size and poverty, so any effects are independent of one another. We also tested for the interaction between these two variables. For more details on our district findings, see Desimone, Porter, et al. (in press).

Appendix

The results from our analyses of longitudinal data are presented in Table A.2. To estimate the magnitude of participating in professional development focused on a particular teaching practice within one of the three areas (i.e., technology, higher order instruction, and alternative assessments), we created two new variables to characterize each professional development activity: the *mean focus* the activity gave to the set of practices within an area and the *relative focus* the activity gave to each of the specific practices in an area.

Mean focus. To assess the extent to which the professional development activity that a teacher attended

focused on multiple, related practices, we calculated the average or mean focus given to the teaching practices we measured. The mean focus for technology use is the average emphasis placed on the four technology practices; mean focus for higher order instruction is the average emphasis placed on the five higher order instructional practices; and for alternative assessments, mean focus is the average emphasis placed on the six alternative assessment strategies. Since each practice is coded 1 if it was given attention as part of the teacher's professional development activity and 0 if it was not, the mean focus for each of the three areas ranges from 0, if no practices within a particular area were covered in the activity, to 0.5, if half of the practices in an area were covered, to 1, if all of the practices in an area were covered. The more practices the activity focused on, the higher the mean focus.

Relative focus. To measure the effects of focusing on one practice rather than another within a professional development activity, we used a measure of relative focus. For example, if an activity focused on two of the four technology practices, including the use of calculators and computers to develop models, the relative focus for the use of calculators and computers to develop models would have a value of 0.5—calculated as the difference between the value of 1 for the use of calculators or computers to develop models and the mean focus of 0.5.

We chose to use mean focus and relative focus to characterize professional development activities because the variables clearly distinguish between the benefits of focusing on one practice

rather than another within a professional development activity (captured by the relative focus) and the benefits of professional development activities that focus on many or few practices (captured by the mean focus).²

Statistical Methods

Technically, our data have a two-level structure, with a set of teaching practices in a particular area (e.g., the set of five higher order teaching practices) nested within teachers. We refer to the two levels at which we have data as the “strategy” and the “teacher/activity” levels. We use the term *teacher/activity* for the teacher level because our data at that level include both teacher characteristics (e.g., subject taught) and characteristics of the quality of the professional development activity the teacher attended in 1997-98.

Given the two-level (strategy-level and teacher/activity-level) structure of the data, we estimated the effects of professional development by using a hierarchical linear model. The model for the effects of professional development on the use of teaching practices in one of the three areas includes the following teacher/activity-level and strategy-level variables:

Strategy-level variables. For each teaching practice within a particular area, we included two variables in the model: the teacher's 1996-97 use of the practice and the *relative focus* given to the practice during the professional development the teacher attended in 1997-98. We also included a set of indicator variables specifying the particular practice. These variables represent the fact that on average, teachers may have increased their use

of some practices more than others over the period under study.

Teacher/activity-level variables. At the teacher/activity level, we included the following variables in the model: the *mean focus* given to the set of practices in a particular area during the professional development activity the teacher attended in 1997-98, controls for the teacher's subject (mathematics or science) and grade level (elementary, middle, or high school), and the *quality* of the professional development (e.g., the time span or degree of collective participation).³

We assumed that two key parameters in the strategy-level model would vary among teachers: the strategy-level *intercept*, which represents the average use of all of the teaching practices in a particular area, in 1998-99, controlling for their use in 1996-97 and for the teacher's 1997-98 participation in professional development; and the strategy-level *slope*, which represents the effects of focusing on one particular practice during professional development on classroom use of the practice in 1998-99. Thus, we modeled these two parameters as random effects. We modeled all other parameters as fixed effects. These assumptions reflect the idea that teachers may differ in the degree to which they changed practice over the period from 1996-97 through 1998-99 and in their responsiveness to professional development. One key analysis question concerns the extent to which a teacher's strategy-level slope and intercept are affected by characteristics of the activities in which the teacher participated—in particular, the mean focus on a set of practices in a particular area and the quality features of the activity.

² The approach we followed is similar to the approach used by Bryk and Raudenbush (1992) to distinguish individual and contextual effects in models involving students nested within schools. In such models, Bryk and Raudenbush propose centering measures of student background on the school mean and entering both the centered student values and the school means in the analysis.

³ Mean focus is a teacher/activity-level variable because it characterizes the activity the teacher attended as a whole (the average emphasis the professional development activity placed on the four technology practices); it does not characterize each strategy separately.

TABLE A.1
The Relationships of Features of Professional Development to Teacher Outcomes

Predictors	Dependent Variables ^a							
	Span	Contact Hours	Collective Participation	Focus on Content Knowledge	Active Learning	Coherence	Enhanced Knowledge and Skills	Change in Teaching Practice
Sponsor								
(1=District, 2=SAHE grantee).....	.27***	.27***	-.13***	.15***	.08**	.01	.02	-.01
	1.25	26.27	-.36	.40	.15	.02	.04	-.02
	(.15)	(3.27)	(.10)	(.09)	(.05)	(.06)	(.06)	(.06)
Type								
(1=Traditional, 2=Reform).....	.21***	.10**	.04	.01	.02	.02	.05*	.04
	.88	9.29	.11	.02	.03	.03	.11	.08
	(.14)	(2.98)	(.09)	(.08)	(.05)	(.06)	(.05)	(.05)
Span								
(1=<a day ... 9=over a year).....				.08*	.30***	.26***	.02	.02
				.05	.12	.11	.01	.01
				(.02)	(.01)	(.01)	(.01)	(.01)
Contact Hours								
.....				.10**	.31***	.16***	.03	.09**
				.00	.01	.00	.00	.00
				(.00)	(.00)	(.00)	(.00)	(.00)
Collective Participation								
.....				.06	.13***	.08**	.03	.02
				.05	.08	.06	.02	.00
				(.02)	(.02)	(.02)	(.02)	(.00)
Focus on Content Knowledge								
.....							.33***	-.11***
							.29	-.08
							(.02)	(.02)
Active Learning								
.....							.14***	.03
							.18	.04
							(.04)	(.04)
Coherence								
.....							.42***	0.21***
							.51	0.22
							(.03)	0.04
Enhanced Knowledge and Skills (EKS)								
.....								.44***
								.39
								(.03)
R² (in percentage)								
.....	12.3	10.5	6.1	11.3	34.9	19.6	51.7	41.6

^a For each dependent variable, standardized regression coefficient (b) is shown on the first line; unstandardized regression coefficient (b) on the second line; standard error (in parentheses) on the third line. Sponsor and type were considered exogenous variables in the model.

* p<.05; ** p<.01; *** p<.001

TABLE A.2
Effects of Professional Development on the Use of Technology

Coefficient	Model 1: Base	Model 2: Reform type	Model 3: Time span	Model 4: Hours
Level 1 model: Use of teaching strategies				
1996–97 Extent of classroom use of strategy, π_2 .....	.462***	.465***	.452***	.463***
Calculators or computers to develop models (0/1), π_3 .....	.076	.071	.093	.099
Calculators or computers for data collection (0/1), π_4 .....	.071	.066	.090	.094
Computers to write reports (0/1), π_5 .....	.179**	.165*	.176**	.185**
(reference category: computers to access the Internet)				
Level 2 model: Teacher/activity-level effects				
Effects on intercept in strategy model (π_{0i})				
Baseline, β_{00} .....	.384***	.449***	.338**	.356***
Mean focus on set of strategies, β_{01} .....	.342**	-.028	.188	.444*
Subject taught: (Mathematics), β_{02}	-.068	-.060	-.078	-.080
Elementary school, β_{03}	-.338***	-.343***	-.352***	-.351***
High school, β_{04}	-.071	-.059	-.055	-.075
Reform type, b_{05}		-.072		
Time span, β_{05} .....			.010	
Hours, β_{05} .....				.001
Collective participation, β_{05}				
Active learning, β_{05}				
Coherence, β_{05}				
Reform type x mean focus, .....		.170		
Time span x mean focus, β_{06} .....			.039	
Hours x mean focus, β_{06}				-.004
Collective participation x mean focus, β_{06}				
Active learning x mean focus, β_{06}				
Coherence x mean focus, β_{06}				
Effects on d_{pi} slope in strategy model (π_{1i})				
Baseline, β_{20} .....	.310***	.235	.139	.299*
Reform type, β_{21}		-.049		
Time span, β_{21} .....			.042	
Hours, β_{21} .....				.000
Collective participation, β_{21}				
Active learning, β_{21}				
Coherence, β_{21}				
Variance components				
Between-teacher variance in intercept .....	.076***	.081***	.080***	.079***
Between-teacher variance in slope .....	.167*	.182*	.184*	.190*
Covariation in intercept/slope .....	.048	.048	.043	.046
Residual.....	.222	.222	.207	.207
Degrees of freedom				
Strategy level.....	351	341	341	347
Teacher/activity level	114	109	109	111

+ p<.10, * p<.05, **p<.01, ***p<.001

TABLE A.2 (Continued)
Effects of Professional Development on the Use of Technology

Coefficient	Model 5: Collective participation	Model 6: Active learning	Model 7: Coherence
Level 1 model: Use of teaching strategies			
1996–97 Extent of classroom use of strategy, π_2 .....	.454***	.423***	.436***
Calculators or computers to develop models (0/1), π_3 .....	.082	.083	.069
Calculators or computers for data collection (0/1), π_4 .....	.071	.081	.078
Computers to write reports (0/1), π_5 .....	.177**	.183**	.184**
(reference category: computers to access the Internet)			
Level 2 model: Teacher/activity-level effects			
Effects on intercept in strategy model (π_{0i})			
Baseline, β_{00} .....	.350***	.368**	.206
Mean focus on set of strategies, β_{01} .....	.328*	.203	.055
Subject taught: (Mathematics), β_{02}	-.082	-.095	-.080
Elementary school, β_{03}	-.348***	-.336***	-.315***
High school, β_{04}	-.055	-.028	-.046
Reform type, β_{05}			
Time span, β_{05}			
Hours, β_{05}			
Collective participation, β_{05} .....	.101		
Active learning, β_{05} .....		.014	
Coherence, β_{05} .....			.033
Reform type x mean focus, β_{06}			
Time span x mean focus, β_{06}			
Hours x mean focus, β_{06}			
Collective participation x mean focus, β_{06} .....	.027		
Active learning x mean focus, β_{06} .....		.019	
Coherence x mean focus, β_{06} .....			.045
Effects on d_{pi} slope in strategy model (π_{1i})			
Baseline, β_{20} .....	.190+	.137	.048
Reform type, β_{21}			
Time span, β_{21}			
Hours, β_{21}			
Collective participation, β_{21} .....	.326*		
Active learning, β_{21} .....		.041+	
Coherence, β_{21} .....			.047
Variance components			
Between-teacher variance in strategy intercept .....	.074***	.075***	.078***
Between-teacher variance in strategy slope .....	.148+	.080	.166+
Covariation in intercept/slope .....	.040	.030	.045
Residual.....	.221	.228	.229
Degrees of freedom			
Strategy level.....	350	332	323
Teacher/activity level	112	106	103

+ p<.10, * p<.05, **p<.01, ***p<.001

Table A.3

Relationship of District Management and Implementation to Characteristics of Professional Development

Predictors	Dependent Variables ^{ab}							
	District Planning	Continuous Improvement	Teacher Planning	Reform	Time Span	Collective Participation	Active Learning	Targeting
Alignment	-.08	.16**	.16**	.15*	-.01	.14*	.04	.17**
	-.03	.03	.03	.01	.00	.03	.00	.04
	(.02)	(.02)	(.01)	(.01)	(.01)	(.01)	(.01)	(.01)
Coordination	.07	.16***	.02	.12*	.03	.05	.07	.05
	.06	.11	.01	.03	.01	.02	.02	.03
	(.04)	(.03)	(.02)	(.01)	(.02)	(.02)	(.01)	(.03)
District-vs. School-Level Planning				-.07	.11*	-.09	-.09	.08
				-.02	.06	.04	.02	.05
				(.01)	(.03)	(.02)	(.01)	(.03)
Continuous Improvement				.06	.08	.13	.20***	.17**
				.02	.06	.02	.07	.14
				(.02)	(.04)	(.04)	(.02)	(.04)
Teacher Participation in Planning				-.07	.03	.08	.20***	.16***
				-.04	.04	.08	.12	.24
				(.03)	(.06)	(.06)	(.03)	(.07)
Reform vs. Traditional					.40***			
					.88			
					(.11)			
R² (in percentage)	6.6	23.0	2.9	6.2	20.6	9.5	23.1	23.0

^a For each dependent variable, standardized regression coefficient (b) is shown on the first line; unstandardized regression coefficient (b) on the second line; standard error (in parentheses) on the third line.

^bThese analyses control for cluster, consortium, size, size by consortium, and poverty.

*p<.05; ** p<.01; *** p<.001

The effects of focusing on a set of practices in a professional development activity can be examined by comparing the magnitude of the coefficients for mean focus and relative focus. If the coefficient for mean focus is higher than the coefficient for relative focus, there is a “spillover” effect in which focusing on a set of related practices has an effect over and above the effect of focusing on an individual practice alone. If the coefficients for the two variables are equal,

focusing on multiple practices neither helps nor hurts. If the coefficient for mean focus is lower than the coefficient for relative focus, it indicates that focusing on multiple practices detracts from the effect of the single practice. Because the effects for mean focus must be interpreted in comparison to the effect for relative focus, the results for relative focus are presented first.

We conducted separate analyses for each of the three areas under study (use of

technology, higher order instruction, and alternative assessments). For each area, we estimated seven models, one including only the mean focus and relative focus and controls, and the others adding each of the six professional development quality features, one at a time. Given the relatively small overall sample size, we estimated separate models for each quality feature instead of including all quality features in a single model.

Using GIS Technology to Support K-8 Scientific Inquiry Teaching and Learning

A model program for using GIS technology is described in the context of science content to help K-8 teachers become proficient in learning and teaching through scientific inquiry.

During the 1980s a revolutionary type of computer software called Geographic Information Systems (GIS) was developed for integrating environmental data bases with automated map makers, using satellites called Global Positioning Systems (GPS) (Audet, Hushold, & Ramasubramanian, 1993). GIS is a tool for spatial data analysis. The typical display of a GIS is a map-based image where layers represent distinct components or types of information (Baker, 2000). These layers can be manipulated, making them accessible to more data than traditional cartography. Educational applications of GIS are gaining attention, and promise to impact classrooms. By emphasizing local information GIS can make learning about the environment relevant and meaningful in a global setting. GIS allows teachers to integrate scientific disciplines in their research efforts to ask questions and solve problems about their environment. With the inclusion of remote sensing, desktop GIS, and Internet-based mapping, teachers are gaining opportunities to become fully immersed in the analysis of spatial data (Baker, 2000). Current science

education research in GIS instruction calls for more teacher workshops to prepare teachers to learn about GIS and apply it in their instruction (Audet & Abegg, 1996; Paladino, 2000).

Using GIS requires a content area as a context (Baker & Case, 2000). The content area and social problem of salmon recovery supports the current elementary and middle school science curriculum and meets the ecosystems standard for national (AAAS, 1993; NRC, 1996) levels. The salmon recovery issue is also a good subject to study because there are so many local influences that can be explored through GIS technology.

The *National Science Education Standards* (NRC, 1996) recommend that all science teachers continue to develop their pedagogy and content

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knowledge through inquiry. Inquiry is defined as raising an investigable question, developing methods to answer that question, carrying out those methods, analyzing the data, and reporting findings and making conclusions. It has been traditionally thought of as difficult to prepare teachers to use inquiry methods to teach science. The goal of the current project was to provide elementary and middle school science teachers with content background and inquiry strategies for delivering effective inquiry instruction for environmental problems such as the salmon issue, through use of GIS technology.

Theoretical Background

Though it has been deemed important to teach science using inquiry methods, it has also been found difficult to prepare teachers to do so, particularly elementary teachers who have limited science backgrounds and likely no experience in actually conducting a science investigation (Kielborn & Gilmer, 1999). Weaker preparation in science could make them weaker in their knowledge of science content (Atwater, Gardener, & Kight, 1991; Schoeneberger &

Russell, 1986), and less confident about their skills in teaching science (Cox & Carpenter, 1989; Perkes, 1975; Tilgner, 1990).

Giving K-8 teachers experiences with scientific inquiry has been shown to improve their understandings of inquiry, hopefully relating to their abilities to apply inquiry to their own teaching (Kielborn & Gilmer, 1999). Additionally, learning in context is important, (Saxe, 1988), and thus, this project used a local controversial science issue as a context for inquiry. Baker and Case (2000) also found that content can provide a context for science teachers to learn to use GIS technology. Thus, the science content provided by investigating the salmon issue provided a context for both science inquiry and GIS technology learning.

The teaching methods used in the project are based on Harlen's (1997) recommendations. Specifically participants were (a) asked to express their ideas about content studied, (b) provided with opportunities for exploration and involvement to develop their knowledge and skills through hands-on inquiry activities, and (c) asked to reflect on their learning to help develop and assess change in knowledge.

Description of the Project

Five primary teachers (grades 1-3), ten middle school (6-8), one para-educator, one school librarian, one high school and one college instructor enrolled in a specially designed summer course at a Pacific Northwest university. Fifteen of those teachers enrolled in the course as a part of their master's program. All teachers but one enrolled in this particular course to learn more about the controversial environmental issue

Table 1. Summary of course participants.

Grade Levels	Number of participants	Teach Only Science	Graduate Student
K-3	5	0	5
6-8	10	0	9
High School	1	1	0
College	1	0	1
School Librarian	1	0	0
Para Educator	1	0	0

of salmon recovery. The librarian enrolled in the course specifically to learn to use GIS technology. One teacher was specifically a science teacher, the rest were generalists without special science training or knowledge. See Table 1 for a summary of participants.

The course instructor formed a partnership with a local company, Soil Search, LLC, who had a specialty with using GIS and GPS technology. The company provided the teachers with training in the use of ArcView GIS 3.2a for both data collection and analysis, as well as training with handheld GPS units (Garmin eMaps). The teachers received a full 7 hour day training from a GIS specialist from Soil Search, LLC, in using ArcView GIS 3.2a, and were required to use it during the rest of the course for data collection and analysis. The specialist was available by phone, email, and often gave face-to-face individual consultations as teachers were learning the software. The specialist was also available at the end of the course for support in analysis of the data.

The course instructor provided instruction in inquiry teaching methods, as well as content surrounding the salmon recovery issue. In the Pacific Northwest this environmental issue

is very controversial. Simply put, the issue surrounds whether, and which, species of salmon are endangered. Contributors to the demise of salmon include but are not limited to: dams, hatcheries, changing water temperature, changing water quality, river habitat, ocean habitats, and over-harvesting of fish at different points of their life cycles (Lichatowich, 1999). Additionally, others question whether there actually is a decrease in numbers of salmon, and raise the point that to fully recover salmon numbers life in the Pacific Northwest would have to return to colonial days. Thus, the science topic was ripe for inquiry, and GIS was an appropriate tool for collection and analysis of data.

Description of Activities

Teachers participated in a 7 hour a day, two week course that focused on learning to teach inquiry science using a real-world problem through GIS technology. On the first day of the course the problem of salmon recovery was identified and clarified, and teachers selected focus groups on which to conduct inquiries. Many issues were identified that were contributors toward salmon recovery, but because of the size and time limits of the class, the focus was limited to

five topics. These five topics generated by the teachers for in-depth inquiry were: dams, agriculture and land development, hatcheries, water and environmental habitats, and Native American perspectives.

The course facilitators organized field trips and speakers that would provide the teachers with diverse views regarding the salmon issues. Ideally, the teachers would seek the information themselves, but given the length of the course this organization was done in advance. Teachers did, however, conduct other research on their own during the course. The teachers heard from selected guest speakers regarding the Endangered Species Act and the Clean Water Act, visited dams to see what ways they were investigating protecting salmon, visited the Conservation District Office, and salmon hatcheries to get perspectives on what is being done to produce more salmon that are genetically hardy and can keep characteristics similar to wild salmon (Levin & Schiewe, 2001). They also heard from a guest speaker from the Umatilla Tribe to hear viewpoints from Native Americans and the role salmon plays in their culture and economy. Additionally, the groups had afternoons to conduct inquiry into their own focus topics, and were charged with writing a summary report and presenting that report orally to their classmates so all shared benefits of their investigations. The culmination of the course consisted of the class debating and making a recommendation for resolving the salmon recovery issue.

Within the scope of the above framework, teachers also learned to use GIS to help collect, organize, analyze, and present their data. They spent one 7 hour session learning

conceptually about GPS/GIS by using the Garmin eMaps, and then learning the ArcView 3.2a software for use during the rest of the workshop. They identified fields and made data collection tables that would serve as a starting point for each focus group. The data collection tables were modified and filled in during the remainder of the workshop as investigations proceeded. The data tables could then be connected to overlaying maps of areas in the Pacific Northwest that matched the data, for instance, for which dams in Washington State had what numbers of fish passing over it during certain years. On the final day of data analysis the teachers were able to combine their data analyses into one layered map in which it was possible to compare numbers of fish going over each dam, to numbers of fish released in nearby hatcheries, to harvesting data, for instance. These numbers could then be converted to layered graphic data, enabling a comparison of different factors.

Data Collection

A three-item content questionnaire was given to all teachers pre and post instruction, as well as an eight-item questionnaire designed to tap their understandings of nature of science

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(See Appendix). There was a strong need for in-depth understanding of teacher conceptions and a desire to appropriately interpret questionnaire responses. Therefore ten graduate students were randomly selected to participate in semi-structured interviews, five pre-instruction, and five post-instruction. The teachers were provided with copies of their questionnaires, and asked to elucidate their points verbally to the interviewer (either a faculty member or trained graduate teacher). This approach allowed the use of the post-instruction interview data both to establish the validity of the questionnaires and facilitate the interpretation of changes in participants' views. The interviews were audio taped and transcribed for later analysis.

The researcher maintained a log of daily class activities, as well as perceptions of teacher learning, use of technology, and inquiry. Teacher logs were collected and read for their developing ideas and understandings of the salmon recovery issue, inquiry teaching, and use of GIS technology.

Data Analysis

Initially the researcher analyzed pre-instruction questionnaires for baseline knowledge about the salmon recovery issue as well as understandings of nature of science. The author sought patterns in her researcher log and teachers' logs for references to use of technology, specifically GIS technology, in teachers' data collection and analysis. Next the interview transcripts were analyzed similarly, searching for patterns in teacher understandings of nature of science as well as salmon recovery, and reference made to GIS technology. Viewing the interview transcripts enabled the researcher to be assured she was

interpreting questionnaire responses appropriately, further enhancing the validity of the analysis. Post instruction questionnaires and interviews were similarly analyzed, resulting in a summary of general understandings held by the class pre and post-instruction. The summaries were sought for patterns or categories, which were checked against confirmatory or contradictory evidence, and were modified.

Pre and post summaries were compared to assess changes in participants' understandings of salmon recovery issues, nature of science, and the use of GIS technology.

Results

Understandings of salmon recovery

There was quite a range of science backgrounds for the participants in the class. Teachers had taken from 3 science credits to 30. Many teachers in the class emphasized education or English/language arts as their undergraduate majors. Thus, teachers were not science specialists. It is not surprising to see that their initial understandings of the salmon issue were not substantial. Table 2 summarizes the pre- and post-instruction responses.

Virtually all teachers who participated in the institute substantially improved their knowledge of the

salmon recovery issue. In their pre-instruction responses to what issues they could identify that contributed to salmon demise only 4 issues were identified, and these were restricted mostly to fourteen teachers stating that dams (14) were the cause of salmon demise, and ten (some identified both) commenting that over harvesting was a contributor to salmon loss. After instruction many more issues were identified, with the responses being mostly to contributions of (a) hatcheries (9), (b) dams (8), (c) culture and society's views, including Native American (7), and (d) water use (6).

Pre-instruction responses to the questionnaire indicate that there were many misconceptions regarding the salmon life cycle. Several teachers did not realize that salmon were anadromous and spent time in both fresh and ocean water. They did not generally know the names of each stage of the life cycle. However, at the post-instruction questionnaire and interview all teachers were able to identify the appropriate life cycle stages, and all knew that salmon trekked from stream to ocean, and back to stream. Several included other details, such as the length of time different species of salmon spent at different points in their travels.

In response to the question of what remediations were already taking



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place for salmon recovery, prior to instruction teachers identified only 9 remediations, with the most common response being the controversial solution of breaching dams (11). Following instruction the types of recovery recommendations more than doubled, with nineteen different responses. The flavor of the responses changed as well. While there were fourteen teachers who included dams on their post-instruction responses, none of them spoke solely of breaching dams, but more of modifications that were being made on dams to make them more salmon friendly.

Understandings of nature of science

Teachers improved in their understandings of nature of science (NOS), as evidenced from a comparison of their pre/post responses on the Views of Nature of Science Questionnaire (VNOS) (See Table 3 for an overview of their responses). Because teachers had a more informed view of elements of nature of science post instruction as pre-instruction, it is likely they will have a more informed view of inquiry.

Prior to instruction most (18) teachers could not state that science differed from other disciplines because it required evidence, and yet after

Table 2. Comparison of pre- and post-understandings of salmon recovery issues

	Pre-instruction	Post-instruction
Number of Salmon issues identified	4	20
Number Accurate Salmon Life Cycle Descriptions	4	18
Number of Remediations Identified	9	19

Table 3. Number of teachers with adequate views of target NOS elements.

	Pre- instruction	Post- instruction
Empirical	0	9
Tentative	4	18
Creative and imaginative	18	18
Subjective (theory-laden)	14	18
Social and cultural	3	11
Observation vs. inference	4	18
Theories and laws	0	5

instruction 9 teachers stated that science was differentiated from other disciplines because it required empirical evidence to make claims. Thus, teachers improved in their understandings of the empirical NOS.

Teachers' conceptions of the tentative NOS also improved. Prior to instruction one teacher believed that once a scientific theory was developed it never changed. Others stated that science finds exact, final answers. Following instruction 18 teachers believed that science was tentative, and with new evidence theories can change, while the teacher who believed that scientific theories never change was now uncertain about her response.

Prior to instruction teachers did not hold complete understandings of the subjective NOS. From post-instruction responses it is evident that teachers improved in their ideas that science is somewhat subjective. Indeed, some of the subjectivity can be due to social and cultural influences, and teachers' viewpoints of the social and cultural element of NOS also improved.

Teachers' views of the distinction between observation and inference also improved. Following instruction

teachers recognized that scientists could use their creativity in interpreting evidence when developing models that represent reality (i.e., an atomic model) whereas prior to instruction four teachers believed scientists had to actually observe and see something to be able to make a claim for their explanations.

Prior to instruction 15 teachers believed that theories are untested ideas, and laws are proven facts. The others believed that theories would become laws after they had been accepted, or "better proven." After instruction four teachers still held that idea, but five teachers held the accepted view that theory is an explanation for a law which is observable, and others had developed similar ideas that were closer to the accepted view.

Use of GIS technology for Inquiry

Four themes emerged from the data regarding how GIS technology can be used to support inquiry teaching and learning. First, it was found that teachers commented both verbally and in their logs about the role of technology, particularly GIS technology, on their learning of the inquiry teaching process. One representative comment was "it

seems that technology is making this data collection both easier and more difficult. It is more difficult at first, but once I get the hang of it, I can organize my data quickly."

Second, when teachers responded on nature of science surveys, they included the importance of GIS technology in helping to develop scientific knowledge and thinking. For example, one teacher wrote on her questionnaire "technology, like GIS is helpful in developing scientific ideas because it can extend your senses, make it easier for you to observe different things." Another said, "The GIS is particularly nice because you can organize your data into different layers and see things you might not have otherwise seen in your data. It can help build scientific knowledge."

Third, teachers mentioned difficulties associated with learning GIS. It appeared very important to have the support available to them to help overcome these difficulties. One teacher mentioned in her log "if it weren't for being able to contact Jason (the GIS specialist), I probably never would have figured out the GIS fields." Another noted, "I'm glad we had work time in the lab while Jason was there. If he wasn't there I might not have figured it out." Another stated in an interview, "usually I just don't have time or the resources to learn a new software program, no matter how beneficial it might be in the long run. It was good to have both the time and the support for learning the ArcView program."

Finally, teachers commented on how they could at last see how inquiry teaching could be approached. They did not get "bogged down" in data analysis, but rather could spend their time interpreting the data as it was displayed in different ways in their

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ArcView program. One teacher stated in an interview “It was helpful to be able to look for trends in the data and see patterns without having to do all kinds of wild calculations. It helped me in interpreting the data.” Another stated on her questionnaire, “I finally get inquiry! It seems I was always so focused on getting the results I never spent enough time figuring out what the results really meant. And that is the real purpose of inquiry!” And finally, from the course evaluation, “This was a great model for inquiry teaching. And using the GIS was scary at first, but really helped when interpreting the data.”

Implications and Conclusions

It is apparent from this study that with time and support teachers can use GIS technology to enhance their inquiry science learning, and hopefully that will translate into a positive teaching experience for them as they put it into classroom practice. From this course the teachers were able

to participate in a scientific inquiry about a controversial topic that generated much interest. They were able to select areas of interest about which to design in depth inquiries, put together the information from their group and other groups’ inquiries via GIS technology, and analyze the data again using GIS technology, making a reasonable recommendation for resolving the issue based on these analyses. They were aware that their recommendations may have been different had they selected to focus on different contributing factors, and if they had more data and information in their given topics as well as how they looked at the data. They gained a better understanding of the tentative nature of science, in part, because they could look at the data in different ways through the ArcView GIS software, allowing them to make better interpretations of the data. Thus, GIS technology in scientific inquiry can possibly influence conceptions of NOS; a topic for future study.

From the teacher logs, course evaluations, questionnaire and interview responses, it is apparent that teachers had an enhanced view of inquiry teaching at the conclusion of the course. Additionally, from viewing their presentations and papers, it is apparent that the GIS technology component enhanced their ability to record, organize, and analyze data allowing them to make important interpretations for their inquiry. A key to the success of the GIS component was the specialist who was able to provide both group and individual support as teachers were using the GIS software. Another key to using the software to enhance inquiry learning was the requirement to do so, and the science content as the context.

Without being required to learn the GIS software, and giving time and support to learning, it may not have been as convenient for teachers to learn the software. Additionally, without the problem-solving context in which teachers desired to find answers to their foci, they may not have seen a need for learning or using the GIS technology. A desire to use the technology to find an answer to their problems, coupled with time and support to learn the technology, helped the teachers use the technology to assist their authentic inquiry.

The authors of this paper recommend that teacher educators who want to promote use of technology by teachers find authentic reasons for teachers to use such technology, to model how

A desire to use the technology to find an answer to their problems, coupled with time and support to learn the technology, helped the teachers use the technology to assist their authentic inquiry.

that technology can be used to support goals teachers must already help their students meet (e.g. national science education inquiry standards), and to provide time and support to those teachers in learning such technology. The authors found the model contained within this report to be an effective way in helping teachers recognize how technology, particularly GIS

technology, can support their efforts in learning and teaching scientific inquiry.

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- Nature of science Questionnaire*
4. After scientists have developed a theory (e.g. atomic theory), does the theory ever change? If you believe that theories do change, explain why we bother to teach theories. Defend your answer with examples.
 5. What does an atom look like? How certain are scientists about the structure of atoms? What specific kinds of evidence do you think scientists used to determine what an atom looks like?
 6. Is there a difference between a scientific theory and a scientific law? Give an example to illustrate your answer.
 7. How are science and art similar? How are they different?
 8. Scientists perform experiments/investigations when trying to solve problems. Other than the planning and design of these experiments/investigations, do scientists use their creativity and imagination during and after data collection? Please explain your answer and provide examples if appropriate.
 9. Is there a difference between scientific knowledge and opinion? Give an example to illustrate your answer.
 10. Some astronomers believe that the universe is expanding while others believe it is shrinking; still others believe that the universe is in a static state without any expansion or shrinkage. How are these different conclusions possible if all of these scientists are looking at the same experiments and data?

Appendix

- Pre and Post-Questionnaires (Content and Nature of Science).
Salmon Questionnaire
1. What issues can you identify that affect salmon recovery?
 2. Please describe the life cycle of the salmon, including its migrations
 3. What kinds of recommendations do you currently know of that are being made to help salmon recovery?

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Teaching to the Science Standards: Stories from the Classroom

Results of qualitative research indicate that although teachers do not object to standards-based instruction, they are not receiving sufficient support to align current instructional and assessment practices with published benchmarks.

Research on Science Standards.

Standards and science. The debate has been in the news since the publication of *A Nation At Risk* in 1983. Researchers have documented the struggles of creating science standards (Kennedy, 1998; Roberts, 2000; Forster & Wallace, 2002), while pointing out the strengths and weaknesses of the current movement in science education (Rodriguez, 1997; Guskey, 2001; Hill, 2001). In recent years, there have been articles dealing with teachers' views and practices in planning science instruction (Levitt, 2002), connections between the nature of scientific inquiry and classroom activities (Keys & Bryan, 2002), teachers' struggles with aligning standards-based science curricula with the needs of diverse students (Ruiz-Primo et al., 2002), and ways to involve teachers in science education reform (Weidenmann & Humphrey, 2002). Few studies, however, look at connections between state standards and the actual process of science instruction.

Some of the classroom-based research focus on connections between the nature of science, teachers' beliefs, and classroom practice (Bryan, 1998; Tobin & McRobbie, 1996; Keys & Kang, 2000). Only recently have

researchers begun to examine some of the connections between science standards and the realities of public schools (Hayes & Deyble, 2001; Puskin, 2002; Barton & Tobin, 2002). According to Spillane et al. (2001), "Because of the nature and magnitude of the reforms, most teachers struggle to understand their substance and their implications for practice" (p. 918). These struggles have been documented in other states that are working toward aligning curricula with state standards and creating statewide assessments. Unfortunately, there have been few studies focusing on Washington State (LaGuardia et al., 1999).

Background on Washington State

The Washington Essential Academic Learning Requirements (EALRs). In Washington State, the EALRs (Washington State Commission on Student Learning, 1998) have affected the way districts approach the teaching of math, reading, writing, and science. The EALRs represent Washington State's translation of the *National Science Education Standards* (NRC, 1996) for districts, teachers, students, and parents. Like the *National Science Education Standards*, these general guidelines are broken down into three categories of benchmarks (K-5, 6-8, and 9-10), which address systems,

physical science, Earth and space science, life science, scientific inquiry, problem solving, nature of science, and science/technology/society. These benchmarks are blueprints for developing grade level frameworks that will help teachers and administrators make curricular, instructional, and assessment decisions. Ultimately, the EALRs and benchmarks will help teachers and students prepare for the Washington Assessment of Student Learning (WASL).

The Washington Assessment of Student Learning (WASL). The WASL, which is administered in grades 5, 8, and 10, is a criterion-based assessment consisting of multiple choice, short answer, and extended response items. Currently, the WASL examination is in the pilot stages, with voluntary participation from schools and districts. However, the 8th and 10th grade assessments will become operational in 2003-04, while the 5th grade assessment will become operational in 2004-05.

With the WASL's operational deadlines looming, partnerships have formed among K-12 districts, business leaders, universities, and informal science education agencies to assist teachers in making the transition to standards-based science instruction.

Some of the work focuses on creating workable frameworks for teachers. These frameworks provide grade level targets in the subdisciplines. Other work is more systemic in nature, involving districts in professional development, assessment, and curriculum development. What all of this work has in common is the desire to help teachers help students meet the goals of the EALRs. The goal of this paper is tell some of the teachers' stories about science teaching and science standards.

Purpose

The purpose of this research study was to examine teachers' experiences with the EALRs and explore the relationships between science standards and science teaching. Specifically, five questions guided this research: (a) What are practicing teachers' perceptions of the Washington State science standards? (b) What are the connections between these standards and curriculum planning? (c) How do practicing teachers address the standards in their classroom instruction? (d) What factors impede or facilitate the integration of these standards into science instruction? (e) What are the connections between these standards and assessment?

Method

Rationale

According to Anderson and Helms (2001), the most promising research on science standards and science instruction will:

- (1) be approached from multiple perspectives,
- (2) be conducted in the "real world,"
- (3) focus on interventions into conventional school practice,
- (4)

not assume that change can be driven from the top down, (5) be interpretive in nature, (6) focus on student roles and student work, (7) give major attention to teacher learning (which includes addressing values and beliefs), (8) attend to parents' concerns, and (9) be approached systematically. (p. 11)

This research project incorporated these criteria into its design. Using an interpretive approach to classroom research (Strauss & Corbin, 1990), I focused on identifying meanings that participants assigned to the EALRs and the WASL. Data were collected over the course of three quarters (September 2000 – June 2001) in which participants were enrolled in three courses at the University of Washington, Tacoma.

Context of the Study

Participants enrolled in three courses, which are required for a study option in science education. The first course, *Curriculum Design and Assessment in Science Education*, explores the relationship between standards and the construction and evaluation of current science curricula. The second course, *Inquiry in the Science Classroom*, examines the connections between these standards and classroom instruction. The final course, *Using Technology in Science Education*, introduces teachers to new technology and how they can use that technology to enhance science teaching.

All classes met for three hours on a weekly basis for ten weeks. Participants explored theoretical and pedagogical issues related to standards-based instruction through required readings. They also engaged in discussions and

hands-on activities designed to explore participants' ideas about standards and how they affect curriculum design, instruction, and assessment. Participants led discussions, gave teaching demonstrations, and wrote critical reflections of these activities. Other course assignments encouraged participants to examine their teaching responsibilities critically and make changes based on their emerging understanding of the science standards. These assignments included personal essays, technology reviews, curriculum analyses, lesson plans and video production.

Participants

Twenty teachers (17 females and 3 males) participated in this study. 19 were public school teachers and one taught at a private religious school. The participants' ages ranged from 22 to 48, with a median age of 33. All participants were working toward a Master of Education degree (M.Ed.) with 12 students declaring a science education study option. With the exception of two participants with science degrees, the science backgrounds of the class members were similar.

Data Sources

Overall, there were four primary sources of data for this study. The first source included audiotaped recordings of all class sessions, including lectures, whole group discussions, and small group work. The second source, videotapes of teacher-led activities, was used by each participant for the reflective assignments and by me as a source for examples of teacher-teacher interactions. Field notes, the third data source, documented contextual, theoretical, and methodological issues as they arose during the classes

(Corsaro, 1985). Finally, the fourth data source included the assignments and reflections turned in by each participant. These multiple data sources were essential for the purposes of triangulation (Merriman, 1988).

Data Analysis

All audiotapes and videotapes were transcribed on an ongoing basis. These transcripts were compared to field notes and emerging themes were noted (Erickson, 1986; Strauss & Corbin, 1990; Bogdan & Biklin, 1992). Through an iterative process of reading transcripts and refining themes, I then looked at work samples to find examples of those themes. At the end of each course, volunteers from the course checked the clarity of the themes and examples from various data sources. Unclear themes were reexamined, revised, and presented again to members for discussion. Finally, I used a reflective journal to track all decisions regarding data collection and analysis during the study; this constituted an audit trail. Thus data analysis occurred throughout the entire research project (Strauss & Corbin, 1990).

Findings

Assertion 1: Teachers are not seeing standards-based curricula.

The teachers in this study knew about the science standards, but have not seen good examples of standards-based curriculum. Of those who have worked with standards-based curriculum, there was a large disparity about what counts as curriculum. For some, the curriculum is just a textbook. For others, a series of kits suffice. Yet, when we explored the idea that a curriculum is more than just books, videos and kits, I was surprised by the

participants' lack of experiences with standards-based curricula.

What counts as curriculum? During the very first class session, I asked a series of questions about science teaching, science curriculum, and knowledge of the state standards. One particular question, "What does your science curriculum look like?" elicited some interesting responses including "Our adopted textbook", "The electricity kit that comes in November", "The FOSS unit on simple machines", and "Whatever I can fit in between reading and math". Stunned by this range of answers, I asked who determines what they teach in science at any given time. The middle and high school teachers gave a variety of answers. "Me", "The department chair", and "The school board" were a few of the responses.

Several elementary school teachers indicated that they were often left to make choices regarding science instruction. Molly, a fourth grade teacher, had an interesting situation in her district:

Rios: And what's the situation in your district?

Molly: Actually we don't even have [a] science [curriculum], we integrate it with social studies. So like when we're studying Indians, we study mechanics or simple machines. I mean, we have it all corresponding, so we don't even have science books, which was really interesting to me. There is no curriculum, no science teachers. We just have a list of trade books, that's what we have for a science curriculum."

Rios: So, who defines the science curriculum?

Molly: I think that teachers individually make it.

All of the elementary teachers in the class identified with Molly's response. Although they taught a range of topics, many of them were on their own when choosing science topics. Some had chosen familiar topics and stuck with them from year to year. Others either waited for preassigned science kits to arrive or avoided teaching science altogether. Betty, who was finding ways to supplement her kits, provided insights about her science teaching experiences in this vignette:

On a Tuesday afternoon while my students were at recess, I carefully set up supplies for the planned science activity on solutions. I poured oil, salt, corn meal, and pepper in small cups and I filled larger cups with water. Each table would have four cups of water, the materials to mix with the water, and a spoon. When the students returned from recess, I explained the activity then passed out the materials. Twenty-two active second graders enjoyed mixing different substances into water. I observed the students and asked them about what they noticed. Some groups just mixed one substance at a time into a glass of water and watched carefully. Other groups began to mix all the mixtures together, spilling on the table and making quite a mess. At this point, I decided it was time for clean up and discussion. It was now 2:55 PM and my students had to be ready to

go home by 3:05. I gave directions to the students to bring the materials to the counter by the sink and wash up any spills. As the students sprung into action, there was much commotion. Some students continued to mix solutions while others began cleaning up. I was helping at the sink when a student came running with a cup of oily water and spilled it on me. I threw up my hands and said under my breath "I hate science!" A student quietly approached me and said, "But Mrs. Ucker, I love science." Followed by others who said, "So do I." When things were finally cleaned up and the students were ready to leave, I felt compelled to explain that I really did like science but I did not like the mess and disorder created during science activities.

Betty is not alone in her struggles. Although she is aware of the science standards, and their emphasis on content and inquiry, she would rather deal with the content and not get into the messy stuff of science. For her, content is easier to teach. Addressing the other areas of the standards (i.e., process skills and the nature of science) required more preparation, management, and materials. Yet with further probing, I learned that despite knowledge of the standards, there was more to what I was hearing than just a lack of curricular materials; there was a lack of standards-based curriculum in their schools.

What counts as standards-based curriculum? Using the *National Science Education Standards* (NRC, 1996) as a guide, we explored what were the key elements of standards-based curriculum. After lengthy

discussions and an essay devoted to the topic, we agreed on 5 key elements. They included 1) explicit connections to targeted benchmarks, 2) developmentally appropriate language and activities, 3) logical sequence of lessons from one grade level to the next, 4) multiple assessments to address content and process skills, 5) and information on prerequisite knowledge and students' misconceptions. With this information in hand, we returned to our initial discussions on curricula. As expected, few students had seen what they believed were standards-based curricula.

Frustrated, they began to discuss what it would take to transform their existing curricula into something that resembled a standards-based curriculum. One teacher, Leslie, was adamant about what she wanted, "The one thing that troubles me whenever I read these [ideas about curricula], they are wonderful ideas and we should employ them in the classroom. But we need more examples and training!" Leslie's outburst was representative of what I heard from other teachers in the study – they wanted to see models of competent curricula and receive training in how to use it. They had had enough of the piecemeal approach of their districts. Rather than having one set of kits in first grade, and a completely different set in second grade, they wanted to see a clearly articulated progression of kits. For these teachers, it's important to know what skills are taught in first grade. Then, second grade teachers can build on those skills and teach new ones, and so forth.

The participants expressed the same concerns about content. Rather than study dinosaurs three times during elementary school and once during

middle school, schools should organize curricula to examine the "big ideas," or unifying concepts, of science. These core concepts (NRC, 1996) include form and function; evolution and equilibrium; constancy, change, and measurement; evidence, models, and explanation; and systems, order, and organization. With an increased emphasis on "big ideas," each grade level could explore topics in each discipline of science. One teacher, Mike, found that no one publisher could provide a curriculum that met his ideas for an effective, standards-based curriculum. He actually found the standards useful in creating assessment tools for examining published curricula. In the end, he and his team had chosen the best models in that curriculum set, hoping to find better matches in other places.

Assertion 2 – We actually don't mind standards, but...

In a recent survey of Washington teachers, I learned that teachers actually felt positive about the science standards in that they provided direction and targets for instruction and assessment (Rios & Beaudoin, in preparation). However, they weren't sure if districts were providing enough guidance for teachers to align instruction with the proposed state assessment in science (i.e., the WASL). With this information in hand, I explored these issues with teachers in my study. Like teachers in the survey, they echoed the same sentiments.

Standards Make Sense. I had prepared myself for an outpouring of anger and angst. After all, the newspapers were filled with stories about WASL boycotts and increasing tensions in schools. However, Debbie's journal entry reflected another important theme in this study.

And see, I used to think that was overwhelming [the EALRs], that was like wow, it's all right here, in one 1-inch book!

Teachers initially felt apprehensive about the science standards, especially those who had not read them thoroughly prior to my classes. After reading through them and examining how existing curriculum addressed the standards, I saw some changes in their perceptions.

Elementary teachers, for one, felt that the K-4 benchmarks were straightforward and attainable. "After all, we know more about this stuff than our kids, right?" Well, yes and no. In biology, for example, they were at ease with the content. "I can teach bugs and plants. I do that already," said one elementary school teacher with confidence. That confidence began to wane when I followed up with "What about simple machines, solutions, and plate tectonics?" Among the most prevalent problems were lack of materials and insufficient content knowledge. Reflecting on a unit on plate tectonics, Kim, a fifth grade teacher, wrote this vignette:

When I began teaching nine years ago, I did very little science in my classroom. In fact, it wasn't until about seven years ago that I began to realize that I was doing a great disservice to my students by not teaching more science. When I came to this realization, I also began to panic because I did not feel like I was really qualified to teach science to my students. However, I decided that I was a qualified professional and I could figure out how to teach some science to my students.

I asked my teaching partner at the time what we were supposed to teach in science. She answered, 'Plate tectonics.' 'Plate tectonics! What do we have?' I answered. "Just a kit on convection." she said walking away. In a panic, I ran out to the local teacher supply store to find some materials because we didn't have many at our school.

Still, Kim found that the targeted benchmarks helped her make decisions about what she needed to learn and what to teach students (e.g., latitude, longitude, and layers of the Earth). The standards, however, did not help her with how to teach plate tectonics and what materials she needed to teach the content effectively.

Materials to meet the standards. Billy, a middle school teacher, faced similar issues as his elementary school colleagues. His excitement for teaching science made a big difference in his ability to overcome a lack of materials and supplies. Billy made connections with other teachers and local suppliers for science materials. Over time, he "kind of accumulated lots of things." But just having materials was not enough to address the issue of teaching to the standards. For some teachers, the issue was finding new ways to teach the content. For others, the standards asked for more than just teaching the content. Students should be able to relate the content to the unifying concepts of science. Most importantly, teachers needed to provide more inquiry-based activities that did more than just reinforce the content; these activities needed to provide more opportunities for doing science as it is practiced. "That is hard with what we have. I mean, I can only do so much with old microscopes,"

said another middle school teacher. Still, they weren't opposed to trying.

One high school teacher, Amy, had established relationships with the science faculty at a nearby university. These faculty members served as mentors, providing content and pedagogical expertise in tough areas like transcription and protein synthesis. Through these relationships, Amy revised her existing curriculum from one that was heavily lecture-driven to one that utilized guest speakers, videodiscs, computer simulations, and video. To her, the mechanism of transcription was made more understandable through these varied instructional strategies. For example, using a film created in the technology class she was able to illustrate some of the major players in protein synthesis, as well as involve students in simulations of transcription. In her opinion, the less she relied on lecture, the clearer the lesson became. "I'm finding that I'm talking less and doing more. The kids really like it." Fortunately for Amy, she had found something that worked. With some time and practice, she would make similar changes in other content areas.

Assertion 3: Practice makes for more practice

One of the luxuries of having the same students for an entire academic year is being able to witness their growth over time. In the three classes used for this study, participants focused on the same topic for nine months. They used these topics to explore issues of curriculum design, instruction, assessment, and technology. I found that these teachers appreciated the detailed work on one area. In their experiences, professional development experiences

on the standards were one shot deals. Someone told them what to do, showed them examples of how it's done, and allowed them to try out these ideas in their classrooms, if time permitted. In the case of these teachers, these three classes were the longest professional development experiences of their careers.

Show me how it's done. Telling teachers what to do only gets you so far. My goal in these classes was to show them how to address science standards from the start. In modeling this approach, I discussed how I started with the standards, decided which ones would serve as foci for my courses, and constructed a sequence of activities illustrating issues of planning, instruction, and assessment. What was most interesting for me was how few textbooks existed for me to use in this process. So, I used a variety of materials, both purchased and created, to meet my goals.

For these classes, I chose the unifying concept of form and function. The specific topic that I used was the skeletal system. I wanted to explore how animals solve issues related to support and locomotion and geared my activities for a 7th grade class. During the first quarter, we explored how I prepared a series of lessons designed to address this topic. The first step was to determine prerequisite knowledge for this topic. Then, I determined what content issues were relevant to this topic and sequenced them accordingly. Only after I was clear on the concept, prerequisite knowledge, and content did I begin to address process skills. For the sake of simplicity, I decided to focus on observation, inference, and data collection. With these decisions made, it was easy to sequence lessons. For the mini-unit on animal movement, the lessons included: (a)

How do animals stay up? (b) How do animals move? (c) How do animals differ in their movements? (d) What's the relationship between support and movement? (e) Why do some animals move differently than others in the same environment?

Obviously these lessons were a snapshot of a full unit, but I wanted to focus our discussions and not get overwhelmed by the scope of the lessons. I also wanted to illustrate the relationship between standards and instruction. In my opinion, standards-based instruction is more than just matching EALRs to lessons; it involves attention to concepts, prior knowledge, and a deliberate sequence of instructional activities. Suffice it to say that teachers were surprised at how much work went into these five lessons. Leslie, after asking how long it took me to develop the mini-unit, exclaimed "A couple of days! And you're an expert. It would take me weeks!"

Let us try. After modeling the phase appropriate to the course (e.g., designing the unit for the Curriculum Design course), it was each student's turn to engage in the same struggle. One particular student, Don, struggled with issues that were common to most teachers. Don struggled with the time demands of the task and needed a great deal of guidance. The realities of teaching school and being responsible for other subjects, like reading and math, kept him from devoting full attention to this task. Instead, he tried a short cut and searched for existing resources and materials. In his opinion, someone else should be doing this work for teachers so that they can get on with the business of teaching.

Is that your job to do that?
[Evaluate curriculum] Do you

think that's your job? I mean, it's a real question. Is it your job to develop those units, or is it the job of somebody else to give it to you to implement? Boy, it'd be nice if it was somebody else doing it.

Despite his protests, Don still tried to revise his current unit – the solar system – into a standards-based unit. Unfortunately, his search for materials came up short. Although he found activities that supported his ideas, he was still faced with the challenge of adapting these activities to meet the benchmarks. For example, Benchmark 1.2.7 states that children should "know that Earth is one of several planets that orbits the sun, and the moon orbits the Earth" (p. 5). Additionally, Benchmark 1.3.6 asks students to "observe and describe the patterns of movement of the sun and moon relative to each other and Earth, and relate them to Earth's rotation" (p. 8). To Don, he faced an impossible task because it was winter in the Pacific Northwest (cloudy and rainy) and he didn't have the students after dark. Moreover, his school couldn't afford to send his class on a field trip. So what should he do?

Like his fellow classmates, Don first made decisions about what to teach. Once he had struggled with the core concepts, process skills, and essential content, he then began to put together a series of lessons that were manageable given his teaching situation. The first try was a compromise. He reconciled (reluctantly) the content that he had to teach with the materials that were available to him. The most important realization was the alignment of lessons with standards, and the potential for future revision.

Ok, want me to start? ... basically what we did was we looked over what materials we had, since all we can remember is we've seen some before but we don't exactly know what's in the closet. Then, we looked over the EALRs, ... So what we're assuming when we teach this lesson is that we will have had a couple of lessons on that before we go into doing this. What we were thinking about doing, is doing a play, debrief, replay type inquiry type lesson. It's gonna change but we wanted to start there and use what we had.

When it came time to actually teach several lessons to his peers, and reflecting on this experience, Don had accepted the standards as guidelines for instruction. He took more responsibility for the direction of his curriculum and had discovered resources available for materials and content advice. Perhaps the biggest advancement involved the use of technology in the unit. Don had searched the Internet for inexpensive simulations and instructional aids and came upon the NASA website (www.nasa.gov). Here he found numerous CD ROMs for teachers, lesson plans, and instructional aids. Most importantly, he experimented with using the Internet as a teaching tool and supplementing his lectures and activities with multimedia. If you knew Don, you would appreciate the magnitude of these instructional choices. In one of his last reflections, Don wrote,

This inquiry stuff is still kinda hard for me. I liked what we did this quarter and tried some stuff out with the kids. For my project [M.Ed. Final Project], I taught

one class the regular way and the other class got inquiry and technology. They're really into it! It's tough on me but the kids like it. That's cool!

Don's struggle exemplifies what most of the teachers struggled with during our year together – finding the time to align instruction with standards. In Don's case, the struggle resulting in a revised unit that incorporated multimedia, hands-on learning, and some lecture/demonstration. He made tough choices and looked for ways to tackle his choices. Most importantly, he had ongoing support from his fellow classmates and me. Planning lessons and teaching turned out to be the easy part; assessment was another story altogether.

Assertion 4: How do you test science skills on a paper and pencil test?

According to the *National Science Education Standards* (NRC, 1996), teachers of science are doing more than just assessing content understanding. If the goal of the standards is to engage students in the exploration of “learning science (understanding content), learning to do science (ability to do scientific inquiry), and learning about science (understanding scientific inquiry)” (Krueger and Sutton, 2001, p. 40), then teachers must do more than provide traditional paper and pencil tests. One of the struggles that we encountered as a class was addressing the NRC charge to use “exercises that closely approximate the intended outcome of science education” (p. 78). Unlike instructional issues, the assessment issue was much tougher to overcome.

I already use multiple assessments. Prior to delving into issues of assessment, I surveyed my class to

determine what types of assessment strategies they used in their classrooms. They listed a number of assessment strategies including quizzes, tests, lab reports, worksheets, and projects. On the surface, it seemed as though they were in a good position to address aligning standards with instruction and assessment. Yet as we began to read the book *A Science Educator's Guide to Assessment* (Doran et. al., 1998), the teachers began to realize that their approaches were all geared for assessing students' understandings of content. Carol, who taught a unit on salmon, was the first one to reach this conclusion. Like other teachers, Carol saw a pattern in her assessments. Many of her questions focused on factual information. How many salmon do you observe in the stream? What color are they? In which direction are they swimming? Even when she asked seemingly open-ended questions, the students could find the answers in their textbook. So what could Carol do differently to make her assessments more authentic?

Toss out the canned stuff. In many instances, adopted curricula provided few answers to questions of authentic assessment. Many times, the curriculum provided ideas for extension, assuming that the teacher understood the extension activity and could create both specific instructional activities and appropriate assessments. In Carol's case, she had neither. Like Don, she started by writing appropriate goals for the unit and identifying important prerequisite knowledge. Unlike Don, she decided to tackle assessment issues prior to constructing (or in her case, revising) instructional activities. For her, assessment would guide her instruction and she wanted to embed assessment activities throughout the unit, not just at the

end. Given the complex nature of the salmon unit, she needed to check for understanding constantly in order to make adjustments to the unit. Her reasons were practical: if they made a mistake, the class would have a number of dead salmon on their hands. That would not only be disastrous for the class, it would also be very expensive. Driven by this urgency, she set out to integrate instruction and assessment.

Pretest, pretest, pretest. Carol's unit involved raising salmon in the classroom and setting them free after a certain period of time. In order to set them free, the class needed to meet certain goals related to the life cycle, nutritional needs, and health of salmon. The curriculum provided sufficient details in each area. It also provided guidelines for feeding and measuring growth and health. Given this information, she still felt the need to determine what her students knew about each area prior to engaging them in the unit.

[I'd] have them take post-its and do simple concept maps on their own. I use them as a pre-assessment. I teach kids how to do concept maps, and I'll say ok, we're going to do something on salmon. I want you to create a concept map of what you know about salmon. ... they would do a concept map, I'd collect them and I would get a sense of what they know. So I use it as a pre-assessment. Not graded at all.

With this information in hand, she could tailor her activities based on the class' knowledge base. It also gave her a good idea on who could be on the feeding team first and how much training to provide in the first few days of instruction. Most importantly, she

could determine what assessments were needed throughout the unit and how frequently she needed to give them.

In addition to collecting content information from students, Carol also took notes on interactions among team members, the types of questions students were asking, and the types of mistakes made during each class session. Much to her surprise, the students did not get bored with the routine; rather, it only contributed to their excitement about the unit. In her opinion, they knew that the stakes were high and took ownership of the project. One student commented that she wanted their salmon "to be the best tasting ones in Washington."

What about the nature of science? Carol's unit turned out very well. She documented content understanding using quizzes, discussion, worksheets, and tests. Daily team reports, observation checklists, and her teaching journal gave her invaluable information about process skills. After several months of working with this unit, another teacher asked Carol how she was addressing standards related to the open-ended nature of scientific investigations. Perplexed, Carol went back to her curriculum and discovered that as much as she tried to work outside the existing curriculum, she had still fallen short of addressing this area of science standards. On the one hand, her students were engaged, had taken responsibility for their learning, and were involved in activities related to issues outside of the classroom. After all, they were taking care of these salmon and planning to release them to the wild in a few months. So what was missing? Many of their activities provided few opportunities for open-ended exploration.

Engaging students in Nature of Science (NOS) activities involved a level of risk not normally found in traditional curricula. It involves not only a change in the types of activities presented, but changes in the conversations among students (Lederman, 1992). In Carol's case, students might experiment with different foods, schedules, and water temperatures to determine what was optimal for raising salmon. They could set up controlled experiments and collect data over time. Carol would also need to provide opportunities for students to present their information and persuade others of the validity of their findings. Given the nature of this particular unit, and the emphasis on not harming the salmon, Carol felt that this unit was not the best one to explore the nature of science using experimentation. She could provide scenarios that allowed students to perform paper and pencil experiments, but she could not afford (literally) to let them experiment with their stock. In the end, she decided to locate current data on salmon survival rates, and have students perform research to determine the potential causes for the trends in the data. To her, this approach allowed students to appreciate the open-ended nature of science, while preserving the current stock of salmon. After presenting this activity to her peers during class, she wrote:

I like doing the salmon unit a lot. I still don't know if I can do much with the nature of science. I can use observations and checklists, bulletin boards, presentations and written reflections. We can even talk to the people at the salmon [research] center about what they do, but it's not the same as doing experiments.

We all learned an important lesson about assessment through Carol's experiences. Assessment is an ongoing activity and it's not always possible to address every aspect of the standards in a unit. What's important is that we use activities that are true to the intended outcomes of our instruction.

Discussion

In addition to discussing directions for future research on standards, Anderson and Helms (2001) provided an overview of what we do and do not already know about implementing science standards. On the one hand, we know that time, changing roles, issues of equity, preparation in standards-based teaching, and the realities of schools all affect how well teachers address standards in their classrooms. Working with these teachers confirms the claims made by Anderson and Helms. These teachers found that teaching to standards meant more than just matching activities to specific benchmarks. They needed to reconceptualize what they were teaching, plan appropriate instructional and assessment activities, and oftentimes engage in activities that were outside of their comfort zones (e.g., technology). Their districts and departments provided only minimal support in addressing the standards in all phases of instruction. And even with some support, issues of time, lack of materials, and pressure to teach reading, writing, and math affected their ability to focus fully on examining their existing curriculum and make substantial changes. With this study, we now join the growing number of studies exploring teachers' struggles with standards-based education.

On the other hand, there are four things that we still need to learn more about: the role of students in

standards-based education, the nature of the desired student work, parental involvement in science education reform, how teachers can best be engaged in reassessing their personal values and beliefs, and how teachers can take major personal responsibility for acquiring needed new professional competencies. This research focused primarily on numbers three and four. Over the course of three quarters, we learned that teachers needed: (a) a challenging and supportive environment to reexamine their current curricular and instructional practices; (b) an iterative forum where they can plan, implement, and revisit their classroom activities; (c) assistance in deconstructing the instructional process into smaller chunks (i.e., concept identification, lesson planning, assessment, and reflection); and (d) to see models of standards-based reform in action, both at the curricular and instructional levels.

Even with the best of intentions, we sometimes miss the mark in implementing standards-based reform (e.g., Carol's struggles with the nature of science). Keys and Bryan's work (2002) provided some insight into the nature of our difficulties. One problem with implementing standards is the lack of understanding about teachers' knowledge base for implementing inquiry. Inquiry is a "cognitively complex process requiring that learners have background knowledge in the scientific concept they plan to investigate..." (p. 639). By extension, if we expect to engage students in this complex process, then it stands to reason that teachers should also have experience in the same process. Although this study did not examine the issues of inquiry exclusively, it does point to similar needs regarding the Standards themselves. If we expect

students to engage in instructional activities related to the Standards, then teachers should also have similar opportunities to engage the Standards.

These opportunities should explore teachers' current beliefs and content understanding, as well as clarify the meanings of each benchmark and implications for instruction. As I wrote in my journal: "One thing that I've learned about the standards is that they don't tell you about instruction, they don't tell you about misconceptions, and they definitely don't tell you much about assessment." In my own attempts at planning a sequence of lessons that were aligned with the standards, I realized how complex this process was. I spent time thinking about prerequisite knowledge, addressing basic skills, sequencing lessons, and incorporating formative and summative assessments. The amount of work for a small number of lessons was staggering! I can empathize with teachers who are asked to do the same work with much larger units of study. "Conceptual learning takes time for reflection, for cycles of experience and discussion, and often included surprises" (Drayton & Falk, 2002, p. 12).

Help is here! In Washington State, there are numerous examples of initiatives that support teachers in their struggles with science education reform. At the statewide level, Washington State LASER (Leadership and Assistance for Science Education Reform) helps teachers learn about the science education standards, examine current practice, and explore successful models of standards-based curricula through numerous projects and institutes. At the district level, the Spokane school district has designed four core science unit outlines

(chemistry, physics, life science, and earth science) at the 7-10th grade levels, examined current curricula materials for alignment with the unit learning targets, adopted appropriate instructional materials, and provided teachers at all these levels with focused professional development (unit organization and sequence, content background, pedagogy, and use of assessment data). Finally, Kentridge High School has worked over the last three years to examine alignment issues related to units on evolution and classification. With the help of experts at both the K-12 and university levels, teachers at this high school are redesigning their formative and summative assessments (see Ketover & Rios, 2002). Based on this initial work, they are beginning to examine assessments in other science subjects.

Conclusion

Science and standards. Some teachers believe that the pendulum of this movement will swing back soon. Others see the immediate impact of reform (e.g., schools on probation, ties between test scores and merit pay, and anxiety among students) and are taking reform seriously. Regardless of their positions on science education reform, they all agree that the EALRs and WASL have changed the way we look at science teaching and learning. Supporting our teachers should be our first priority if we are to “leave no child behind” during our quest for national excellence in science education

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Science Leadership In an Era of Accountability: A Call for Collaboration

Collaboration is described as an important component in achieving meaningful leadership initiatives at the local, state, and national levels.

America's public schools encompass an amazing diversity of unique communities and constituents, so diverse in fact that they are immune to sweeping, generalized descriptions. But it is now conceivable to characterize the focus of American public education using one catch-all term: accountability. High-stakes assessment, standards-based curriculum reform, and the notion of teaching-to-the-test are certainly not novel or even recent developments in the education profession, though it is arguable that they have never saturated local, state, and federal practice and policymaking on such a sweeping nationwide basis. Accountability, in any of its manifestations, is woven through state and federal education legislation, local school board meetings, newspaper articles, re-election speeches, journal reports and professional conferences; science educators, parents, and citizens find it everywhere they turn.

How does the current context of accountability and high-stakes consequences impact the nature of science leadership? What strategies will foster more and better science leadership in this new era? This article examines ways in which science educators can address the challenges and mandates of the

accountability movement through increased collaboration, forming networks to support sustainable, meaningful leadership initiatives at the local, state, and national levels.

The Changing Context of Science Leadership

The role of science leadership has changed significantly in the past decade alone. Hounshell & Madrazo (1987; 1997) found that over a ten-year period, the definition of the science supervisor's role remained ambiguous, perceived differently by principals, district administrators, teachers, and the supervisors themselves (Madrazo & Hounshell, 1987; Hounshell & Madrazo, 1997). Characterizing the identity, role, and objectives of science leaders today is complex, at a time when science instruction appears to have been set back as a lower priority in the general public and political conceptions of what matters in many K-12 schools. Today's science educators face a nationwide challenge that is unequalled since the Sputnik crisis of the 1950s. The nation's increasingly politicized focus on reading, writing, and math high-stakes testing has led to federal funding cuts to science education, and mounting evidence of lagging student science achievement.

Science supervisors across the United States grapple with ways to reform curriculum and instruction in some consistent, meaningful manner, using guidelines such as the National Science Education Standards (NSES) (National Research Council, 1996). At the same time, an increasing body of empirical evidence supports the advantages of progressive, inquiry-based science instruction, showing that it contributes to improved student achievement in reading, writing, and math as well as science competency (Klentschy, Garrison, & Amerol, 2001; Einstein Project, 2001; Jorgenson & Vanosdall, 2002). Ironically, the nation's political leaders, as well as the public, are generally less receptive to the results of these data than at any time in the recent past.

Nonetheless, the charge to science teachers, coordinators, and supervisors is to identify and implement meaningful solutions to reform the systemic weaknesses pinpointed in American K-12 science education. Researchers, including Valverde & Schmidt (1997) analyzed the fundamental reasons for the shortcomings in student science achievement data provided by the Third International Math and Science Study (TIMSS) (2001), and they argue that the challenge to science

leaders is profound at every level of leadership. From the classroom to the state department, educators call for reform: deepening and narrowing what is taught, reducing redundancy, and critically examining the merit of the so-called spiral curriculum, navigating overstuffed but underdeveloped textbooks, and resisting the temptation to simply impose upper-grades courses on younger students in an attempt to emulate TIMSS countries that are considered successful. The scope of the necessary reform ranges from unifying the nation's local school districts behind a common set of standards on the national level, to training teachers and providing resources for better science instruction – including resource-poor rural and urban schools – at the local level (Schmidt, McKnight, & Raizen, 1997). It is a daunting charge for science leaders everywhere, a huge task at every level of leadership.

Further, the science leader's job description has expanded, adding another layer of challenge that impacts the effectiveness of teachers, coordinators, and supervisors alike. According to Zuckerman (1997), science leadership now entails a wider spectrum of collegial and managerial functions than ever before, beyond improving curriculum and instruction. Some science supervisors are called to provide guidance and resources for science teachers, serving as mentors and administrative liaisons; others have evaluative responsibilities, often delegated by overburdened site administrators; and a third group struggles with the difficult task of providing colleagues with support and guidance while conducting those same teachers' evaluations. Wildy & Wallace (1997) assert that, "science leaders have responsibilities ... to

actively and explicitly help colleagues improve their performance by developing trusting collaborative relationships that focus on their improvement" (p.14). The instructional specialist function is laudable and yet complex, perhaps unrealistic, for some individuals in science leadership roles, such as principals in underserved schools who lack the subject expertise, site personnel, or district-based resources to offer such help. All these challenges, within the broadened scope of the science leader's role, are complicated in the context of increased accountability, particularly in schools and districts where resources and support for science instruction are diminished by emphasis on "The Three Rs."

Finally, science leaders themselves must be identified in the new era of high-stakes testing and basic skills priorities. Traditionally, science leaders included state science supervisors, district science supervisors, building-level science curriculum specialists, science department heads, and faculty at colleges and universities. Recently, social and educational changes, especially the focus on accountability, have resulted in a diversified science leadership: superintendents, state education officials, building principals, lead teachers, mentors, and nationally-organized coordinators such as Building a Presence: Key Leaders and Points of Contact (National Science Teachers' Association, 1995). All these play increasing roles in local science decision-making. While these individuals worked for student learning and school improvement in the past, systemic change requires their increased collaboration for the purpose of empowering networks dedicated to improving student achievement in science. This new collaboration takes shape at a time when such efforts seem

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more urgent, but less widely received, than in any recent era of American K-12 education.

How the Accountability Era Impacts Science Leadership

Science education reform must now advance, and some aspects of science leadership may be at risk. As the public eye moves away from the state of science readiness in the K-12 population, and legislation from the federal and many state governments diverts funding once used to promote science instruction toward other curriculum priorities, science educators must encourage a new generation of science leaders to take charge, despite a grim short term outlook. First, the charge to science leaders must be re-evaluated and focused to reflect the new realities in American public education. Years of research and investigation led to Project 2061 (1989) and NSES (1996); it must now be codified and promoted beyond the readership of the professional journals or the attendees at science education conferences and workshops.

To this end, the NSTA Committee on Coordination and Supervision of Science Teaching (work in progress) developed a position statement addressing the nature and objectives of science education leadership. Twelve educators representing K-12 schools, state departments of education,

educational support organizations, and higher education gathered to help redefine and flesh out the key responsibilities of today's science leader, in conjunction with the framework established by NSES. Drawing from a wealth of information from sources such as the NCMST (2000), TIMSS (2001), analyses including Valverde & Schmidt (1997), and pivotal work by other experts, committee members brought from their own experiences helpful guidelines for today's leaders in science education. The committee found that the essential priorities and responsibilities for developing and promoting science leadership for the future include:

- Ensuring that all students have the opportunity to achieve science literacy
- Aligning district curricula, instruction, and assessment with national and state standards
- Articulating a district's pre-K through 12 science program
- Implementing effective professional development based on district needs and objectives
- Managing resources that support standards-based instruction
- Selecting and retaining excellent teachers
- Collaborating with post-secondary institutions, community organizations, and businesses (NSTA Position Statement, work in progress).

All these responsibilities of science supervisors are essential in realizing a meaningful, lasting, systemic implementation of the NSES. Fundamental to all of these important duties, and to the very nature of science leadership in the current era of accountability, is the

Science leadership entails responsibility for identifying and promoting effective teaching, professional development, assessment, content, program, and system reform.

last objective: determining how to increase collaboration.

How Science Leaders Can Enact Reform: Collaboration is the Key

Science leadership entails responsibility for identifying and promoting effective teaching, professional development, assessment, content, program, and system reform. None of these important functions can be aligned and coordinated in a national science reform effort without deliberate measures to increase collaboration among current and future science leaders. Meaningful collaboration entails great determination, hard work, compromise and diplomacy. It is not only feasible; it is happening among science leaders on the national and local levels. The following are some examples.

Grassroots Collaboration at the Local Level: Science Coordinator Associations

Excellent science instruction takes place in schools in every state. Sometimes teachers at a single school move against the tide of the surrounding district in establishing a science magnet, or one district with a vision for science stands alone in

a state. One teacher in a grade level or department, who has embraced national standards and oriented instruction toward learner-centered, inquiry-based strategies, functions very differently than colleagues using more traditional teacher-centered, text-bound methods in the same grade level and subject area. Many excellent science educators operate in relative isolation in their K-12 schools, and this isolation undermines their ability to spread ideas, to mobilize reform, or to lobby for change.

Elmore & Burney (1998) assert, "the enemy of instructional change ... is isolation" (p.8). Fullan & Hargreaves (1996) state further, that true reform requires "trust in expertise and in processes of collaboration and continuous improvement" (p.100), rather than the efforts of a certain individual in a leadership role. Accordingly, meaningful reform efforts must systematically integrate collaborative practices into the day-to-day routine work environment in U.S. schools. From national and state leaders to the classroom teacher, collaboration and ongoing communication need to increase along two dimensions: among peers at each level, and among the various levels of science education leadership. Major challenges facing science education leadership involve removing barriers that restrict collaboration, while installing systems that facilitate it. In some cases, the shrill call for accountability and the simultaneous de-emphasis of science have become the very catalyst to awaken collaboration, in earnest.

Arizona, and other states contending with high stakes testing, share similar challenges and constituencies, who have labored to initiate science reform despite funding cuts and isolation from

Major challenges facing science education leadership involve removing barriers that restrict collaboration, while installing systems that facilitate it.

one another, from the state department of education, and from the state's universities. Last year (2001), with the announcement of the state science test mandated by the federal No Child Left Behind legislation, science coordinators from several Phoenix-area districts gathered for the first time in a decade to share ideas and develop a collective strategy to prepare for the looming state test, and to discuss other obstacles to reform common to their separate programs. At this first meeting, the Greater Phoenix Science Coordinators Consortium (GPSCC) decided on the following principles to guide its future collaboration:

1. It is illogical for districts to solve problems individually, in isolation, which may be shared by all members or which may have been successfully addressed already by one or more member districts.
2. There is strength in numbers. The more members GPSCC enlists, the louder its voice in influencing the decisions of the state department of education and the state's legislators.
3. For the collaboration to be sustainable, it cannot rest on one district's shoulders. (Members

decided to rotate meeting sites and share responsibility for communicating, organizing, and recruiting/mobilizing new member districts.)

4. Collaboration must take place in an atmosphere of sharing rather than the competition that previously existed between certain districts. (This is addressed through a periodic exchange of news, resources, and tips on "what works," as well as inclusion of teachers and teacher leaders in all planning sessions with the goal of developing a cadre of future coordinators with a shared, proactive, collaborative outlook.)
5. Consortium meetings must have clear goals and a central speaker or theme, so that the meetings do not become simply social occasions to exchange concerns and complaints while accomplishing little.

The principles took hold; and in Arizona, this grassroots effort has expanded at an astonishing pace. Four member districts gathered for the first meeting in the fall of 2001. By its second meeting in April 2002, GPSCC included representatives from over twenty K-12 districts, including Arizona State University, the Arizona Science Center, and the Phoenix Zoo. Initial communications between GPSCC and the state department of education were promising, in terms of the state's shift toward involving educators in the realignment of state standards leading to the testwriting process. By the consortium's third meeting in September 2002, the host district had to find meeting space for representatives from 45 members,

and the group was renamed Arizona Science Coordinators Association (ASCA) to reflect its statewide membership.

At this third meeting, members celebrated the news that key leadership spots had been reserved in the state's alignment and testwriting planning team for association delegates. In the new era of accountability, the ASCA membership is keenly aware that the nature of the state's science standards and its eventual statewide assessment will largely dictate the nature of the science that is taught in Arizona schools; as such, having a voice in the process simultaneously signaled the association's political clout (strength in numbers) and a reason for optimism unknown prior to the first collaborative foray. The association's successful push for representation in the standards alignment process was a small but important victory for science, teachers, and children in Arizona. True "grassroots" hope, energy, and planning propelled the state's fledgling science leadership organization toward a first step in realizing statewide science reform in Arizona. This model of local collaboration is flexible, dynamic, and replicable in any state's science reform initiative.

Collaboration Between Districts and States, Organized at the National Level: NSTA'S Building a Presence for Science

The National Science Teachers Association (NSTA) launched the Building a Presence for Science program in 1995 to address science reform in a nationwide, systemic manner, and to end the isolation of classroom science teachers. The two-fold mission of the program is to end this isolation and to provide teachers with professional

development opportunities, as well as science teaching resources aligned with national and state standards. Such systemic changes will facilitate collaboration along a continuum from national science education leaders to the classroom teacher, and the goal is to connect statewide efforts in an expanding network of science reform across the United States.

Building a Presence works as an intra- and inter-district vehicle for collaboration. For example, in Virginia, a state-level participant in the program, district science supervisors regularly meet under the guidance of state science supervisors to review national and state goals in the context of local needs. Mass mailing and group e-mail are utilized to distribute information from the state to all science supervisors enrolled as Key Leaders. In turn, Key Leaders forward information to Points of Contact (POCs) at each school in the state. The role of the POC, then, is to disseminate this information to all science teachers in that school. Communication can also be streamlined by distributing information directly from the state level to POCs at each school.

It is important to note, however, that this communication is not "one-way." The Building a Presence communication structure is designed for teachers to have access to local and state science supervisors, making leadership responsive to local needs in a feedback-rich environment. Virginia Beach Schools, for example, implemented a system networking science department chairs, program Points of Contact, and subject-specific facilitators under the coordination of the district science supervisor. This system enhances teacher collaboration within and across schools, exemplifying the pattern that Building a Presence

offers science leaders on a national scale. The direct contact provided in the NSTA program among science supervisors, the state level, district and site coordinators, and teachers is an excellent model for articulated collaboration, linking the levels of science leadership.

Collaboration at the National Level: Initiatives for Systemic Change in Science Leadership

Models of collaboration serve to develop leadership at the site, district, and state levels, and NSTA's program facilitates a national structure of local collaboration; however, what vision can direct meaningful collaborative local and state reform efforts, assimilating the national standards into best instructional practices? So doing would incorporate the current context of accountability and fundamental benchmarks for science reform, such as are suggested by Rutherford & Alhgren (1990), TIMSS (1997), Schmidt, et al., (1997), and MCMST (2000).

Since 1989, Leadership and Assistance for Science Education Reform (LASER), a joint effort of the National Science Resources Center (NSRC), the Smithsonian Institute, and the National Academies, has provided national and regional weeklong institutes dedicated to guiding educators who seek to improve science education at the local, state, national, and international levels. The institutes include intense training in best-practice science instruction and curriculum design, professional development, materials and resources, assessment, and enlisting community and administrative support for science reform, all guided by the NSES and supported by corporate sponsors including DuPont, Michelin, Hewlett-

Packard, and BMW. Districts teams taking part in the LASER training week are charged with developing a workable draft of a strategic plan for science reform, under the tutelage of experienced LASER mentor leaders, customized to meet the needs and challenges of their specific learning communities.

The hub of LASER's success in training nearly 1,000 school teams in 13 years has been the program's emphasis on the collaborative nature of effective science reform. Each LASER workshop helps science educators come together with community partners, scientists, corporate advocates, university science faculty, and science advocates from twelve U.S. and international participant teams to share ideas, examine common problems, and determine the best strategies to enact reform given their individual needs and circumstances. Thus, LASER provides a template patterned after the fundamental reforms outlined in the national standards and advocated by leaders in science education, industry, and national science policy that is individually tailored to meet state and local needs of the science teachers, leaders, and the families served by their respective schools. The central element of LASER's success is the opportunity for ongoing collaboration among local, state, national and international science leaders, engendered by a week of intensive, exhausting, and highly relevant training in science reform. The LASER project is linked with other national reform initiatives such as the Association of Science Materials Centers' (ASMC) Next Steps Institute, which serves to assist districts in implementing the strategic plans developed in the LASER experience.

The Future of Science Leadership and Reform: Standing Together

Some educators in states and districts contend with the realities of accountability and high-stakes education, and the day-to-day experience is analogous to passing through the stages of grief for a loved one. At first there is denial, then a protracted period of anger at the source of the grief; next comes depression, followed by a period of gradual resignation; and finally, acceptance occurs. One must only visit a staff lounge in schools during the first few years of a statewide graduation test implementation to see the steady, predictable progression through the grief process and feel the pain of educators struggling to let go of a bygone era while simultaneously comprehending the new age of accountability that has arrived, and will not soon pass.

Clearly, the accountability movement has profoundly impacted science education and science leadership in this nation's public schools, as well as postsecondary institutions that train teachers, coordinators, principals and superintendents. If science educators are to cope with the de-emphasis on science as a core subject, they must find ways to more effectively interact with other K-12 science leaders, community representatives, university colleagues, and other science-interested professionals. This is particularly important in states where science is not part of the testing mandate, and therefore less urgent than the academic subjects connected to school funding, labeling, and teacher pay. There is reason for hope, swept along by many promising developments in science teaching and learning, such as those described

in this article. However, given the storm clouds gathering ahead, science educators must bind together, locally and on a nationwide scale, and push through reform efforts from which science education will emerge intact, well-funded, and widely regarded as an essential learner skill. Collaboration is the key to achieving such meaningful, lasting, systemic science education reform.

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