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Getting from Here to There: The Roles of Policy Makers and Principals in Increasing Science Teacher Quality

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Abstract   In this study we investigate how federal and state policy makers, and school principals are working to improve science teacher quality. Interviews, focused discussions, and policy documents serve as the primary data source. Findings suggest that both policy makers and principals prioritize increasing incentives for teachers entering the science teaching profession, providing professional development for new teachers, and using students' data to evaluate and improve instruction. Differences between the two leadership groups emerged in terms of the grain size and practicality of their concerns. Our findings indicate that the complexity of educational challenges to improve science teacher quality call for the co-construction of policy by multiple constituent groups including school principals, federal and state policy makers, and science education researchers.

Keywords   Science education · Science teacher quality · Policy · Principal community

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Introduction

Science and modern technology are the cornerstones of economic growth in the United States (National Research Council (NRC) 2006). Unfortunately US students in the areas of science and mathematics lag behind other technologically advanced countries in the world (e.g., National Science Board (NSB) 2004; Schroeder et al. 2007). Even in California, the biggest employer of high-tech personnel, students are among the most poorly prepared in the nation in science (California Council on Science and Technology (CCST) 1999; National Center for Education Statistics (NCES) 2000, 2006; National Education Goals Panel 1998).

Research suggests that students' success in science is determined by the quality of their teacher when controlling for non-school factors (e.g., Darling-Hammond 2000; Ferguson 1991; Johnson et al. 2007; Rivkin et al. 2005). A tremendous gap exists between the demand for and supply of highly qualified science teachers (CCST 1999; Center for the Future of Teaching and Learning (CFTL) 2007). Teachers are too often unprepared in terms of both their science subject matter and pedagogical knowledge (NSB 2004; NCES 2004). Science teachers' content knowledge (e.g., Goldhaber and Brewer 1997, 1998; Monk 1994) and pedagogical content knowledge (e.g., Croninger et al. 2007) positively correlate with student achievement. Unfortunately students' access to high quality teachers is uneven (Akiba et al. 2007; Peske and Haycock 2006). The number of under-prepared math and science teachers in California who serve schools with the highest proportion of minority students is four times greater than that in non-urban settings (CFTL 2006).

There are numerous policies at the state and federal levels aimed at improving teacher quality. The no child left behind (NCLB) legislation reauthorizing the Elementary and Secondary Education Act requires that every classroom have a highly qualified teacher, defined as one who has a bachelor's degree, full state certification or licensure, and knowledge of the subject matter that they teach (US Department of Education 2004). To support that effort, NCLB includes a teacher quality program in which districts may use Title II funds to train teachers and/or recruit new teachers (Simmons et al. 2005). Under the Title II Higher Education Act reauthorization, the US Secretary of Education is required to issue annual reports to congress on the national status of teacher quality and teacher preparation. The first US Department of Education Report (2002) emphasizes two principles related to the recruitment and preparation of future teachers:

- Raise academic standards for teachers.
- Lower barriers that prevent talented people from teaching.

The second Department of Education Report describes the states' implementation of these principles to improve teacher preparation programs (US Department of Education 2003).

The recent NRC (2006) report *Rising above the Gathering Storm* calls for immediate government action to improve teacher quality in the Science Technology Engineering and Mathematics (STEM) area. Recommendations prioritize

- Recruitment annually of 10,000 new science and mathematics teachers through the use of 4-year scholarship awards.
- Strengthening the skills of 250,000 teachers through summer institutes, master's degree programs, and professional development for teaching Advanced Placement and International Baccalaureate courses.

This report was cited by several federal and state policy makers in our study as a primary document informing their work for improving science teacher quality.

Educational policy researchers look at the issue of science teacher quality and classroom practice through analyses of policy documents (e.g., Darling-Hammond and Youngs 2002; Marx and Harris 2006), national quantitative data (e.g., Akiba et al. 2007; Darling-Hammond 2000), institutional analysis (e.g., Burch 2007), and implementation cases (e.g., Kellor 2005; Ryan and Ackerman 2005). This study focuses on the professional perspectives and actions of national and state policy makers and school principals as they address the problem of science teacher quality. The following research questions guided our study:

- How is the issue of science teacher quality addressed by federal and state policy makers?
- How do school principals customize these policies and create new policy solutions to improve the quality of science teaching in their schools?

Theoretical Framework

Policy provides a useful "map" for making sense of the terrain of social issues in education (Adams and Krockover 1998). For the purpose of this research we define policy as a deliberate course of action that guides decisions to achieve specific goals within an institution, organization or state. It involves issues of management, resource allocation, and/or power distribution. In education policies involving the federal, state, district, school, and classroom levels may interact, conflict or complement each other (Hall 1992). For example, federal and state policy makers create broad maps that communicate vision and guidelines addressing national and statewide issues of science teacher quality. One such federal guideline includes increasing the quantity of individuals entering the science teaching profession. School principals, on the other hand, create customized policy maps with finer resolution that fit their individual, local school needs. In terms of increasing the quantity of science teachers, some principals partner with local teacher education institutions to recruit the best available science teachers. The problem of improving science teacher quality ultimately requires effective interaction between the federal and state policy makers and the school administrators.

The premise that interaction among policy levels creates more effective policy solutions is rooted in a social constructivist point of view (Berger and Luckmann 1966; Latour and Woolgar 1979). According to this view, policy making is essentially an interactive process. It is not a top–down process in which local leaders implement policies made by higher level agencies, or a bottom-up process in which

state and federal agencies respond to the needs of ground infrastructures. Instead policymaking and implementation are viewed as co-construction processes. Federal and state policy makers, local school leaders, teacher unions, and parents associations share a common goal to improve science teacher quality. However, because each has a different role in solving this problem, healthy conflict and frustration often arise among these constituent groups. Although federal and state policy makers provide guidelines for districts and schools, it is essential that federal and state policy consider local school implementation issues. Conversely, district and school leaders need to understand the rationale and fit between the federal and state policies and local school goals in order to create their own policy solutions (Jones 2003; Spillane 1998). This dynamic process, in which stake holders from various levels "assume control" (Fuhrman and Elmore 1990), "craft coherence" (Honig 2004), and "level the playing field" (Hall 1992), transforms existing policies and creates new ones that more powerfully address the issue of science teacher quality. Different perspectives among the various levels of stakeholders function as the driving force for policy co-construction. Unfortunately, cooperative interaction among stakeholder groups is quite rare.

In this study school principal perspectives are juxtaposed with federal and state policy maker views concerning approaches to improve science teacher quality. This provides a vivid picture of the dynamic processes, from the perspective of the federal and state policy makers and school principals, that need to be involved in policy creation and implementation to create solutions that meet the needs of schools facing diverse challenges.

Methodology

Data Collection

In this paper, data are extracted from two larger studies. One study focuses on interviews with federal and state policy makers (Shen et al. 2007). The second involves data from a community of principals engaged in a 4-year implementation of technology-science curriculum (Gerard et al. 2008).

Federal and State Policy Data

Interviews were conducted with federal and state policy makers to understand their goals, action items and information needs in the area of science education reform. Table 1 summarizes the number and roles of these participants.

Researchers conducted one structured interview with each policy maker either by phone or e-mail (for interview questions, see Appendix). Each phone interview lasted about 30–45 min. All phone interviews were audio recorded. We also collected public documents from the policy makers' Web sites including press conference records, policy maker statements on teacher quality and/or science education and legislative bills. Some of the federal and state policy makers also sent

Table 1 Federal and state policy maker participants

Policy levels	Roles	Participants (N = 13)
Federal	Congressional leaders	1
	National teacher union leader	1
State	State superintendents	4
	State school board presidents	3
	State curriculum commission chair	1
	State senators	3

Note: Only participants relevant to the current study are included here

us supplementary documents that described their policy initiatives for improving science teacher quality.

Principal Data

The second data set includes four, 2-h meetings from a principal community that met regularly to discuss issues related to integration of a National Science Foundation (NSF) funded technology-enhanced science curriculum, called TELS (http://telscenter.org/) (see Bowyer et al. 2008, for further information regarding the principal community). These meetings focused specifically on implementation of local school policy to improve science teaching and learning. We used the federal and state policy maker interview questions and key quotes from the federal and state policy maker interviews to initiate the principals' discussion during these meetings. Seven middle and high school principals from one school district participated in these meetings as shown in Table 2.

The seven principals in the community were a convenience sample selected for a larger study on developing school leadership for technology-enhanced science curriculum. The principals were selected based on criteria that they had at least one teacher implementing the NSF TELS curriculum, and were located geographically close to one another. At the time of this study, the principals had been meeting every 6 weeks, for two and a half years to discuss issues of instructional leadership and science curriculum reform. This made them an ideal data source, as they had built a

Table 2 School backgrounds of participating principals

Principals	School level	School diversity[a]	Students eligible for free lunch (%)
FH	Middle	Medium	4
SQ	Middle	Medium	16
VV	Middle	Medium	15
GB	Middle	High	70
CP	High	Medium	7
MT	High	High	45
CV	High	Medium	10

[a] School diversity is divided into three categories based on the percentage of non-white student population: high (>50%), medium (20–49%), and low (<20%)

high level of trust and collegiality within the group that allowed the participating principals to openly share their views and collaboratively build ideas. The researchers organized and facilitated these meetings.

As shown in Table 2, despite the geographic proximity of the schools in the principal community they were quite different from one another. In terms of socioeconomic status schools ranged from 4% of their students eligible for free/reduced lunch to 85% of their students eligible. Principals were equally divided in terms of school level with 4 middle school principals and 3 high school principals. Principals' experience ranged from one to 9 years.

The school district in which the principal community schools were located is in an urban-fringe area on the west coast of the United States. It is a medium sized school district including 56 total schools. During the time of this study, the district was experiencing a dramatic shift in its student demographics. The percentage of English Language Learner and Special Needs students was increasing significantly while the overall student enrollment was rapidly declining. The school district reported that technology integration was a priority but like most school districts there were minimal resources including computers and/or professional development to guide and support its use. Located in California, the district faced challenges much like the rest of the state, in terms of the supply of, and demand for highly qualified science teachers (California Commission on Teacher Credentialing 2007). Additionally, the NCLB, the California science standardized test, was being piloted in several of these principals' schools at the time of this study, and all principals anticipated high stakes state testing in science, just like in language arts and mathematics, by the following year. This put pressure on the principals and the teachers to ensure that science instruction covered all of the state science standards during the school year.

All principal community meetings were tape recorded and transcribed. In addition to the principal meetings, school policy documents such as school site plans and NCLB accountability report cards were collected.

Data Analysis

We transcribed verbatim all federal and state policy maker interview and principal meeting data. The lack of high quality teachers in science emerged from the federal and state policy maker data as the most frequently mentioned issue with regard to their current policy initiatives in science education. Based on this finding, we decided to focus on science teacher quality in our analysis. We separated all data focused on science teacher quality in both the federal and state policy maker and principal data sets.

We used three emergent categories to code this data: recruiting science teachers, retaining and improving science teachers, and evaluating science teachers. Recruiting teachers addresses bringing candidates into the teaching profession, competing for candidates from a small pool, and attracting people from areas outside of the teaching profession. Retaining teachers addresses improving current science teacher quality through professional development, and keeping science teachers in the profession especially in high poverty schools. Evaluating teacher

quality addresses criteria for determining the effectiveness of science teachers and teaching strategies.

Within each of these three categories—recruitment, retention and development, and evaluation—we identified the federal and state policy makers' and school principals' specific actions and challenges. We selected examples in each category that showcased (a) the differences and similarities between federal and state policy maker and principals' approaches to improving science teacher quality, and (b) the strategies principals used to navigate federal and state policy to address local, science teacher quality needs.

Validity of the analysis was improved by triangulation of the data sources including federal and state policy maker interviews, principal community meetings, public policy documents and school policy documents. The research team continuously checked the accuracy of the researchers' coding by reviewing the coding rubrics and coded data. We acknowledge that, although not included in this study, district administrators (Spillane 1998) and science teachers (Shulman 1987) play an integral role in creating and implementing policy to improve science teacher quality.

Findings

Findings are organized into two sections: (a) a general overview of federal and state policy makers, and local school principal approaches to improving science teacher quality, and (b) specific examples of principals' navigation of federal and state policies and customized solutions.

Overview of Policy Approaches to Improving Science Teacher Quality

Table 3 summarizes the interview data with federal and state policy makers on the issue of science teacher quality. Federal and state policy makers' approaches to recruiting qualified science teachers focus on using financial rewards by means of teacher salary increases or tuition scholarships. The financial rewards are primarily used as an incentive to encourage individuals who hold a BA in science or work in science industry to enter the teaching profession. Policy makers also report modifying teacher credentialing requirements, and reshaping teacher development in terms of preparation programs and mentoring. These strategies aim to increase the number of science teacher applicants by lowering the requirements to enter the profession, and subsequently providing higher quality and more intensive guidance.

Approaches at the federal and state level to retain and improve science teachers include prioritization of professional development for principals and teachers and integration of innovative curricula and school structures. Federal and state policy makers place a particular emphasis on creating mechanisms to improve teachers' use of technology in science. The rationale behind this is that by providing teachers untraditional opportunities for professional growth in the science discipline, such as experience working with cutting edge technologies like GPS, they are more likely to improve the quality of their instruction, and remain passionate about their work.

Table 3 Summary of federal and state policy makers' issues, policies, and challenges for improving science teacher quality

Issues	Policies	Challenges
Recruit qualified teachers	Financial rewards	Attract teachers
	Educational loan forgiveness programs	Attract teachers with science subject matter knowledge
	Tuition assistance for teachers in rural and high poverty schools	Attract teachers with technological skills
	Incentive pay for teachers in rural and high poverty schools	Attract teachers who can implement reform curriculum
	Credentialing	
	Certification requirements waved/ modified for retired teachers and industry professionals	
	Teacher preparation	
	Mentoring/induction programs	
	Improved teacher preparation programs	
Retain and/or develop qualified teachers	Professional development (PD)	Data
	Technology delivered PD	Need data on model curricula
	Continuing teacher PD	Need student data on the effectiveness of different instructional approaches
	Principal/instructional leader PD	Need school site implementation data on science instructional programs
	PD partnerships (higher education, research institutions, and businesses)	Need data on use of technology to improve science teaching
	Schooling innovation	Equity
	Technology instruction	Make technology curriculum affordable and accessible
	Model curriculum	Change science teacher beliefs to "all students can be successful"
	Reformed school structure	Deliver PD to rural and high poverty schools
	State standards	Pedagogy
	Science standards revision	Make science subject matter relevant to industry applications
		Keep teachers up to speed with state of art science and technology
		Create interdisciplinary approaches to science education
		Resources
		Provide adequate technology lab facilities to support science teaching

Table 3 continued

Issues	Policies	Challenges
Evaluate qualified teachers	Assessment Use of state student test score data to measure teacher quality Assessment systems that inform and evaluate instruction Standards Teacher certification standards revision	Assessment Need student data on effectiveness of instructional approaches Standards Identify the science concepts and skills that are important to teach

Additionally, policy makers stress the revision of state curriculum standards in science as a way to improve instruction. An improved list of essential topics, and the appropriate sequence for learning them, could provide teachers with a guide for high quality instruction.

Federal and state policy makers' strategies to evaluate science teacher quality focused on the increased use of quantitative student learning data to measure teacher quality, and inform instructional changes. Policy makers reported student state standardized science test scores as one potential data source, as well as the creation of an assessment system that provides regular feedback to inform instruction. They view the revision of teacher certification standards as a strategy to reframe how we currently evaluate prospective science teachers, broadening the criteria to prioritize teachers' work experience and demonstration of teaching skills in the classroom.

As shown in Table 3, federal and state policy makers identified the challenges that they face in creating policy to improve science teacher quality. Policy makers repeatedly cited their difficulty in attracting individuals to the teaching profession who have adequate subject matter knowledge and are capable in using innovative science technologies. Financial incentives, although helpful, cannot make up the difference in salary between a position in science industry and the teaching profession.

With regard to retaining and/or developing qualified teachers, policy makers report a serious need for data, particularly quantitative, that document the effectiveness of various teaching approaches. Policy makers report that most of their data is collected by word of mouth, white papers, Web sites, and research conducted by their staff. The level of specificity and accessibility of peer-reviewed articles in science education journals prevents policy makers from using these as a data source.

With regard to evaluating teacher quality, policy makers are challenged to determine the key science concepts and processes that should be addressed during each year of secondary science education. Although they form committees of experts to update the standards particularly at the state level, there is often disagreement, and a need for constant revision to keep pace with current scientific findings.

Table 4 Summary of principals' issues, policies, and challenges to improve science teacher quality

Issues	Policies	Challenges
Recruit qualified teachers	Reward structures	Credentialing
	Higher pay for teachers in high poverty schools	Meet state teacher credentialing requirements in science
	Innovative curriculum to attract new teachers	Teacher union policy
	Hiring	Provide differential pay to teachers protected by the Teachers' Union
	Expert teachers involved in recruiting process	Teacher preparation
	Temporary non-credentialed teachers or long-term substitutes to fill gaps	Meet school hiring criteria in area of technology
	Partnerships with local teacher preparation programs	
	Industry professionals	
Retain and/or develop qualified teacher	Professional development (PD)	Teacher union policy
	Mentor teacher positions to provide PD	Meet union policy for teacher contracted work hours when providing PD
	Release time for PD	
	PD for new teachers	Resources
	PD for innovative curriculum	Build partnership with community and industry to provide resources
	Cross disciplinary PD	Apply for grants for technology funding
	Partnership with industry to provide PD	
	Resources	Apply for grants for PD funding
	Technology curricular resources	Meet state planning requirements for PD funding
Evaluate qualified teachers	Assessment	Assessment
	Use of state student test score data to measure teacher quality	Reach state students' proficiency level on science standardized test
	Common student assessment within a department to compare teaching quality	Teacher union policy
		Measure teacher quality based on state student test score data

Table 4 summarizes the principals' issues, polices and challenges with regard to improving science teacher quality.

Principals' decision making in terms of recruiting qualified science teachers focuses on attracting the best candidates to their school, as opposed to increasing the overall pool of science teacher applicants. Principals reported increasing incentives such as small financial rewards to lure science teachers to particular schools, and partnering with industry and local higher education institutions to hire teachers. Principals report building relationships with the local colleges by visiting their job fairs and participating in research projects.

With regard to retaining and or developing science teacher quality, principals use multiple strategies to support professional development of novice and experienced science teachers, and make curricular resources such as computers available to

science teachers. Principals' policy making in terms of evaluating qualified teachers focuses on developing student assessment approaches that can provide an evaluation of teaching strategies and simultaneously inform future lesson planning. The current data sources do not provide principals, they report, with information in time that it can be used to make instructional changes for the particular student population. Additionally, principals wanted rich qualitative data that could provide teachers with greater insight into their students' reasoning.

Principals' challenges, as shown in Table 4, are primarily a function of the federal and state credentialing, teacher union policies, resources, and student testing policies. In the next section, we provide specific examples of principals' adaption and creation of school level policies. In essence principals report being constrained in terms of their authority to make particular decisions such as requiring after school professional development, or implementing project-based science curricula that involves long-term investigations and subsequently explicitly covers fewer state science standards.

Recruiting, Retaining, and Evaluating High Quality Science Teachers: Principals Navigate Federal and State Policy and Customize Local Solutions

The following examples focus on principals' approaches to recruit, retain and evaluate high quality science teachers. We describe the federal and state policy context as reported by the participants in our study and how the local school principals navigate through the network of policies and customize their own solutions to improve science teacher quality in their schools.

Recruiting Science Teachers

The gap between the supply and demand for highly qualified science teachers is a serious problem that has persisted for over five decades (Cohen-Vogel 2005). It remains the focus of federal, state, and local policy makers' attention today (California Commission on Teacher Credentialing 2007; US Department of Education 2003). One federal congress member in our study remarked: "how do we make teaching a viable career choice for college students with a major or interest in science and technology?" (PMI-14. Henceforth, PMI-x' refers to Policy Maker Interview, the xth policy maker). Principals deal with the day-to-day implications of this issue. One principal complained: "There are no science and math teachers out there to hire for our open science teacher positions. We went to job fairs the other day to find several new science teachers and it was just empty, there was nobody there" (PCM, April, 2007. Henceforth, PCM refers to Principal Community Meeting). Another principal explained, "We cannot find a science teacher with enough experience in the actual science subject matter so we have teachers substituting in those classrooms… I even had to sub in there one day!" (PCM, December, 2005). Clearly increasing the number of highly qualified science teachers is a goal for both federal/state policy makers and local school principals. While federal and state policy makers and school principals frame similar strategies to recruit highly qualified teachers, their perspectives on these strategies differ.

Recruit from Industry   Federal and state policy makers in our study suggest ways to minimize or wave the credentialing requirements as a policy strategy for recruiting science teachers from the corporate sector. Some suggest the provision of test-prep courses to help former industry professionals pass the state science teacher credentialing test. One state superintendent explained.

> One approach is to recruit industry professionals, those who might work at Intel or an insurance company who have good math and science skills and might want to become teachers. This policy would provide funding for districts to run test-prep courses so these people could take the courses to help them prepare for the state required subject matter exam. This policy is mostly for more high school level science teachers preparing for a single subject credential. (PMI-12)

One principal in our meetings expressed a positive experience working with teachers recruited from the corporate sector. She explained, "I have someone who is retired from a corporate agency that got her teaching credential. She's spectacular…she must have taught during her career within private industry somewhere… She's been with us four or 5 years now." (PCM, April, 2007). Some other principals, however, were skeptical:

> It's interesting that there's a movement that comes and goes about granting special status to those people from the corporate sector…. They argue that if you have a real strong science and math background policy makers should waive some of the credentialing requirements around the science content because your work in the industry gives evidence that your knowledge base is substantial. (PCM, April, 2007)

Yet these principals felt that such recruitment programs overemphasize content knowledge and ignore pedagogical knowledge. One principal described his experience with science teachers recruited from the industry sector:

> I've had some of these people recruited from industry jobs and they have not worked out…. They were very difficult to work with… and they left after two years. They just demanded things that they felt they should be getting such as X amount of computers in their classrooms…They were used to an industry where they could get what they wanted whenever they wanted in terms of resources…They also felt that they work way too much for what we are paying them. So these teachers have not worked out… and now I'm very leery of these policy approaches because they're not preparing teachers properly for what teaching is all about. (PCM, April, 2007)

This principal observed that teachers recruited from industry in her school lacked a commitment to the profession although they knew the science content. After the teachers learned the availability of resources and the work schedule (e.g., low payment, long working hours, low support), they quit.

Our data show that recruiting teachers from fields outside of teacher preparation programs has pluses and minuses. Industry provides individuals with strong background science knowledge, yet the corporate sector and the classroom are two

very different worlds. Making professionals' career transition smooth is both a federal/state policy issue and a practical action agenda for school administrators. From the principals' comments, simply providing test-prep courses is not enough to make it happen. Innovative, practical programs that provide sustained support to help these individuals make successful career transitions are needed.

Use Innovative Curriculum   Federal and state policy makers and principals report the value of integrating technology in the science curriculum as an approach to recruit high quality science teachers. Federal and state policy makers are uncertain however with regard to the specific role computers should play in science teaching. One of the state superintendents asked, "What is the teacher's role in effective technology use? What type of teacher training is needed to develop proficient use of technology in the classroom?" (PMI-10). Principals on the other hand described their successful experiences implementing innovative technology-enhanced science curriculum, and framed this curricular innovation as a potential strategy to attract science teachers:

> Introduce technology-enhanced science curriculum to teacher education programs…, that could be a hook if a student teacher knew that this kind of curriculum is going to be at their school. That would be a technological link that might be attractive to them. It's something that would put them on the cutting edge. (PCM, February, 2007)

Another principal described how she worked cooperatively with her lead science teacher, an expert with the schools' innovative technology-enhanced science curriculum, to organize the hiring process of new science teachers (PCM, January, 2007). Together they revised the interview protocol to elicit potential applicants' views concerning the use of technology in the science classroom.

Although principals frame innovative curricula as a way to recruit new science teachers to their schools, they also described the challenges. Principals frequently stated that schools need greater resources to purchase and maintain technology related materials for the science teachers. One principal reflected on a recent district-wide science curriculum adoption meeting:

> The teachers went nuts during the meeting when we began to review this technology-based curriculum. A lot of teachers' responses are just negative simply because of their frustration over the lack computers and software that works in our schools and that can be counted on. The teachers didn't want to be held hostage to have to use those machines so they advocated for non-technology based science curriculum… (PCM, February, 2007)

The district teachers union presented additional challenges to principals seeking to improve their technology resources. According to the principals, their district level teachers union opposes allocation of money for technology support because they argue that the money should be used to increase all teachers' salaries and benefits.

Principals also recognized the need for teacher professional development to support teachers' ongoing use of innovative technologies. One of the principals

remarked, "Science teachers, by themselves in their individual classrooms… they'll keep teaching the traditional science curriculum… Technology and innovation just won't catch on unless there is a culture of support for them" (PCM, December, 2007).

Our data suggest that the use of modern information technology should be prioritized in recruiting science teachers. From the principals' perspective, this could be a "hook" to science student teachers, and help principals identify the potential science teacher candidates that are open to and able to engage in instructional innovation. Professional development is needed to support new teachers continued use of technology-enhanced instruction. From the federal and state policy maker's perspective, research is needed to effectively identify the teachers' role in using technology in the classroom, as well as professional development models. This presents a clear and critical role for science education researchers. Communicating our findings to policy makers through white papers and, or easily accessible Web sites can help them to create funding for programs that provide schools with innovative technology resources and the appropriate teacher supports for technology-enhanced science instruction.

Retaining/Developing Science Teachers

High rates of science teacher turnover and limited science subject matter knowledge among the veteran teaching staff presents a significant challenge to improving science instruction (Marx and Harris 2006). Federal and state policy makers and school principals agree that science teachers need ongoing professional support to improve school science teaching and curricula. A state school board president reported "One of our central discussions this year was how we help teachers stay up to pace on the latest state of art science technologies" (PMI-6). Some states in our study are creating programs that allocate funds for science teacher professional development in specific technologies. A state superintendent of instruction reported "The Geospatial Instructional Applications Initiative involves science teachers in regionally conducted, high-quality professional development institutes to learn global positioning system (GPS) hardware and geographic information system (GIS) software" (PMI-7). Research suggests that professional development can improve science teacher quality although many hours over several years are needed (Fishman et al. 2003).

Customized Professional Development The principal community created a space for principals to customize federal and state policies in professional development and generate tailored solutions to address their school needs. Middle school principal GB was skeptical of his teachers' capability to integrate innovative technology-enhanced science curricula:

> I had to fire one science teacher and fill the space with a sub…How could I require this sub or my other new science teachers to use technology yet—it is just way too much…they are really only focused on classroom management right now. (PCM, April, 2006)

Principal GB viewed the "gap" between the teacher capability required by technology-enhanced science curriculum and his teachers' capability as too large to require new teachers to use innovative technologies. GB's colleague in the principal community, Principal FH, suggested a strategy that leveraged their school district's current science textbook adoption process:

> A summer workshop for teachers to see how technology-based science curricula can go hand-in-hand with the new science textbook that the district is adopting could be a really valuable thing. All of our science teachers are starting off with this newly adopted textbook in the fall. If we have a workshop to identify how and where technology can supplement their text, rather than function as just one more add-on, our teachers are more likely to get on board. (PCM, April, 2007)

Principal SQ suggested creating opportunities for GB's new teachers to observe the more experienced teachers in her school using technology-enhanced science curriculum:

> You know what might be helpful too, I encourage my staff to get out and look at teachers using innovative technology in other schools, other classrooms, and I think that's invaluable especially if you don't want teachers to wait until a summer workshop to see what using technology in their teaching is all about. (PCM, April, 2007)

After listening to his colleagues, Principal GB reconsidered:

> I realize I am talking out two sides of my mouth, but although I said I can't require teachers to use technology, I know that as the principal I am the one that has to move in that direction… (PCM, April 2007)

Ultimately Principal GB organized requisite staff development for all the science teachers in his school to learn the TELS technology-enhanced science curricula pedagogical approaches and content. At the last data collection point for this study, over a third of the teachers in Principal GB's science department were teaching with the TELS modules.

In sum, teacher professional development is essential to developing and retaining high quality science teachers from both the perspective of the federal and state policy makers and the principals. The federal and state policy makers emphasized the need for teacher professional development particularly with innovative science technologies, and some policy makers were established such programs in their states. The principals created professional development solutions that addressed their school needs such as supporting new teachers' use of technology, and leveraged the resources in their school district such as the recent textbook adoption and cross-school collaboration.

Build School Leadership   Federal and state policy makers in our study report building school principal leadership as a central strategy in developing and retaining high quality science teachers. One state superintendent reported that recent policy

initiatives aimed at "taking to scale pilot efforts to help principals become better instructional leaders" (PMI-2). Another state superintendent reported that a major policy initiative is to "sustain and scale-up a state agency effort that improves elementary and secondary science education through leadership development" (PMI-13). Principals and policy makers agree that their own professional development is key to improving teacher quality. The principals in this study participate in regular leadership development focused on science and technology. One principal reported "(Our teachers) see that we are supporting them by participating in professional development ourselves. My coming to these meetings means a lot to them. They've told me that." (PCM, February, 2007). In fact, these principals' participation in the ongoing leadership development led to significant increases in the numbers of their teachers using innovative, research based technology-enhanced science curricula (Bowyer et al. 2008).

The principal community created opportunity for principals to share their approaches to supporting science teachers, and borrow ideas from each other. Over time the principals crafted school level policies that improved their science teachers' capacity to integrate inquiry-oriented, technology-enhanced curricula into their teaching repertoires, as shown in Table 5.

As shown in Table 5, the policies centered on the prioritization of resources for science teachers, and the provision of teacher professional learning activities. The principal's policy actions to improve the quality of science instruction in their schools gives evidence for the power of a community of principals model to develop leadership in science. This model, and other effective approaches to developing school leadership in science should be communicated by science education researchers to federal and state policy makers, just as the current programs implemented by policy makers should be evaluated to ensure their success.

Table 5 School policies implemented by principals in the community to support integration of technology-enhanced inquiry science

Policy actions for scaling TELS	SQ middle school	VV middle school	FH middle school	GB middle school	MT high school	CP high school	CV high school
Purchase computers for technology-enhanced inquiry science	•	•	•	•	•	•	
Schedule computer lab for technology-enhanced inquiry science	•	•	•		•	•	•
Principal as delegate on district leadership committees to promote technology-enhanced inquiry science	•	•				•	•
Policy to create teacher hiring criteria for technology-enhanced inquiry science	•		•				
Integrate technology-enhanced inquiry science into school site plan	•	•	•				
Policy mandated use of technology-enhanced inquiry science in science curriculum	•	•	•				

Evaluating Science Teachers: Complexity of Educational Settings

Teacher evaluation is a complex process and ranges from subjective self-performance ratings to the use of objective student performance data (Alicias 2005). The NCLB legislation requires that all science teachers have (a) a bachelor's degree in the subject that they teach, (b) demonstrated pedagogical and content knowledge on a state teaching examination, and (c) completed a state approved teacher preparation credentialing program. The US Department of Education (2003) argued that according to research, teachers' cognitive ability, classroom experience, and content knowledge (in that order) contribute the most to students' achievement. The Department of Education also argued teachers' experience in teacher preparation and/or certification programs is yet to show its effectiveness. In contrast, Darling-Hammond and Youngs's (2002) suggested that teacher preparation does contribute to teaching effectiveness and alternative certification programs produce mixed results.

Credentialing   State law requires every teacher be credentialed. Due to the extreme shortage of qualified science teachers, principals are challenged to find teachers with appropriate credentials to fill their science classrooms. One principal related an example of a "good" veteran science teacher who tried to pass the renewed state test nine times. Each time the teacher only passed a few sections. The principal had no alternative but to fire the "good" teacher and hire substitute teachers to fill the gap. He commented:

> You deal with the quality issue and the quantity issue. And it wasn't like I could select from 10 different people. It's either this person or have a sub start the year…and obviously…I'm saying, 'Can this person (the sub) get from September to June without causing too much damage to kids?' That's a horrible way of existing, but that's the reality… (PCM, April, 2007)

Furthermore, based on principals' observations, teachers without credentials may be good practitioners; they can manage classrooms and actively engage students. One principal remarked, "We all have some excellent teachers, that are natural teachers, and then you pull them out of what they're teaching because of credentials" (PCM, February, 2007). Another principal added:

> One (teacher) had passed the test but I wouldn't have hired him in general circumstances. But I had to hire (him) because I was facing the year with a sub and in my school and the sub just gets destroyed unless he's really strong. So I hired this individual so that I could get by (for) the year and had to fire him before the next year (began). (PCM, February, 2007)

Although these principals' personal judgments on teacher quality carried bias and politics (Glass and Martinez 1993), they captured aspects of teacher effectives that eluded state credentialing tests.

Standardized Test and Collaborative Teacher Constructed "Common Test"   Standardized testing itself is controversial in educational reform (McNeil 2000; Sanders

and Horn 1995). Many teachers are concerned that their academic freedom is jeopardized (Alicias 2005). They are reluctant to be judged by student test scores. But the policy makers' in our study wanted quantitative data such as students' performance on standardized tests to help make policy decisions regarding the evaluation of teacher effectiveness (see Table 3). Principals in our study, like federal and state policy makers, also wanted systematic student data to improve teaching quality. Yet their approach was fundamentally different. Principals wanted to use student assessment data as a tool to facilitate improvement in the quality of teaching, as opposed to evaluating the quality of teaching.

One principal in collaboration with her teachers introduced the "common test" approach to improve the quality of teaching, and ideally, students' performance on the standardized tests as well. The common tests were created by all teachers in the science department focusing on learning goals that the teachers agreed are critical to students' development of coherent understanding of science concepts and processes. All teachers at each grade level administered a common test for each unit, and were thus able to analyze their results across multiple classrooms. The idea of the common test has several potential benefits: (a) teachers can use the evidence from the common test to reflect on their practice; (b) teachers can analyze results across classrooms to generate rubrics that capture a wide range of student thinking; (c) teachers can compare common test results across classrooms to try to identify "best practices"; (d) and teachers can form a community by constructing test items together. In terms of providing learning opportunities for teachers, the common test is different from the state test. One principal noted its usefulness for helping teachers improve their practice throughout the school year:

> (The state test) gives summative results at the end of the year. I want formative assessment and that's what the common test does. Formative allows our teachers to make changes to their curriculum and their teaching strategies. They can also create student progress benchmarks for the different topic areas. (PCM, February, 2007)

Another principal noted the usefulness of the common test in terms of teacher accountability "It's one thing when you have (the state test), teachers can kind of bluff under that radar screen a little bit to claim that the (state test) is just a bad test…" (PCM, February, 2007). The common test approach was opposed by some teachers however, the principals in our study reported, because the teachers were resistant to be judged by any test whether it was the state standardized test or a school common test. A principal pointed out:

> If everyone takes the same test and your class is the only class that doesn't do well in polynomials; you haven't taught polynomials correctly. The other teachers did something different. Instead of looking at that and saying, 'Okay, what did you do that I didn't do, so I can bring that in?' They look at it as if you're attacking them. You're saying that 'I'm not a good teacher'. And the union is right behind them on it. (PCM, February, 2007)

Furthermore, the creation of common assessment items may be problematic. One principal stated: "That's the problem with trying to create common assessments: If

it's handwritten by the teachers, it's going to be the prejudice of the person who actually writes the test, because that's how they taught the unit but not necessarily how somebody else taught the same unit" (PCM, February, 2007). There has to be some kind of mechanism to prevent personal bias when teachers create the test items. The principals also mentioned time concerns since "teachers basically have to give up their own time to create these tests. There isn't time in the schedule." This means that schools and districts need to put effort to provide professional development to create common assessment.

In summary, the complexity of crafting effective teacher evaluation policies and practices requires the involvement of stakeholders from all levels. Credentialing evaluations could benefit from self, peer, and principal observation and reflection on classroom teaching. While state tests encourage accountability, the common test provides learning opportunities as well as formative evaluation tools for teachers.

Discussion and Policy Implications

Similarities and differences emerged with regard to the policies to recruit, retain, and evaluate science teachers reported by the federal and state policy makers, and local school principals in our study. Both groups made policies to increase incentives for those entering the science teaching profession, provide professional development for new teachers, and use students' data to evaluate and improve instruction.

At times federal and state policy makers' and principals' approaches conflicted. The principals in the study reported that at times the federal and state polices created challenges to their work. For instance, state legislation created pathways to ease the teacher certification requirements for industry professionals that wanted to become science teachers. Although this increased the available pool of science teachers, it, in some cases according to the principals, brought about teachers who lacked the pedagogical knowledge to effectively facilitate classroom science, and a commitment to the profession. An additional challenge was the NCLB legislation requiring that all teachers have full and current state certification or licensure in the subject that they teach. Although this requirement improves the quality of science teaching, it exacerbated the science teacher shortage in some of our principals' schools. Principals in our study found that one or two of their most experienced science teachers no longer met the current credentialing requirements for their subject. This was particularly true for science teachers who majored in one subject area as an undergraduate, but taught two different science subject areas. These teachers needed to pass the state science content requirements to demonstrate their subject matter knowledge. If teachers refused to take the test or were unable to pass the test, the principals needed to replace, from their perspectives, these pedagogically skilled "good" science teachers with short- and, or long-term substitutes.

While federal, state policy, and local school policy differ with regard to the policies they make and challenges they face, they still function together to improve science teacher quality. For example, while state and federal policies provide financial rewards to increase the number of qualified teachers, the principals provide

practical strategies including integration of innovative curriculum, partnerships with local teacher preparation programs, and involvement of expert teachers in the hiring process. In a similar vein, principals who work in high-poverty schools benefit from state and federal policies that provide extra financial resources for teachers that work in areas of need. Based on our data and interpretations, we make the following policy recommendations.

Recommendation 1: Increase the Number of Channels for Communication Among Policy Makers at Different Levels

Currently principals are individually subjected to a strong voice from the state and federal policy makers: approaches to recruit, retain, and evaluate quality science teachers are dictated from the top. Creative and successful solutions to practical problems with regard to improving teacher quality, as we documented in this study, are rarely able to emerge from the ground up to inform broader state and federal policy decisions.

Efficient, convenient, and direct channels built into the education infrastructure among different levels of policy makers have the potential to generate policy solutions that are evidence based and responsive to schools practical issues in improving teacher quality. Potential collaboration opportunities include Web sites or blogs that promote information sharing between schools and policy makers, rotating positions for principals as state and federal policy consultants, short-term "internships" for policy makers in schools and principals in federal and state legislative offices, and professional development workshops involving policy makers at different levels in evidence-based debates regarding what is required to effectively teach science.

Recommendation 2: Form Communities of School Principals to Improve Science Teacher Quality

The data from this study suggest that principals, when working together in a community, can and do create school level policies to improve science teacher quality (for how to successfully build and sustain such community, see Bowyer et al. 2008). Principals are able to borrow ideas from each other, and run low-cost experiments to verbally test out new policy ideas in their unique school environment. In this study the principals generated and ultimately implemented policy strategies to recruit, retain, and evaluate science teachers. Policies included forming partnerships with teacher education institutions, creating student assessment systems that provided the basis for teachers' collaborative learning, increasing technology resources, and creating professional development opportunities for innovative technology-enhanced science instruction.

We call for actions at the district and state levels to provide funds to make principal communities feasible. With access to more information than federal and state policy makers or principals in isolation in terms of pedagogical approaches and incentives for high quality instruction, principals can work together to generate effective policy strategies to improve science teaching in their unique school

environments. Currently, the typical school system restricts cross-school dialogue among principals focused on instruction (Elmore 2000). As one principal in our study pointed out:

> Our staff development consists of going to these talking head meetings where they just give you all these binders and you walk out of there more overwhelmed than when you came in…There is no time to actually reflect and really talk about curriculum and teaching. (PCM, April, 2007)

The principal community described in this chapter provided a promising alternative with demonstrated results on improving instructional quality.

Recommendation 3: Call for Educational Researchers to Attend to Policy Issues

Our last recommendation addresses the community of educational researchers, particularly science teacher education researchers with regard to improving science teacher quality. Shavelson (1988) argued that it is critical for educational researchers to understand policy maker and practitioners' "mind frames" in order to improve communications between these two groups, and the researchers. Principals and policy makers cannot directly take action based on educational research but rather there is an "art of problem framing and implementation" (Shavelson 1988). Principals' actions are informed by policies and school contexts just as policy makers are informed by educational research and local needs.

We presented the data from this study to a collection of highly respected science education scholars that were in a meeting to work on a collaborative book synthesizing research on science curriculum design (Kali et al. 2008). We asked the researchers to frame their findings in a way that could inform the questions raised by the policy makers in our study. Resoundingly researchers responded that they did not have had adequate evidence to inform broad policy decisions, nor they did feel responsible for playing a role in policy formulation.

Based on the data from this study, it is clear that federal and state policy makers need research and empirical evidence to inform their work. Evidence of improving science teaching is substantial and needs to be framed in a way that is comprehensible and useful for policy makers. Without such evidence, policy makers, as they reported in our study, will continue to experience a dearth of data on variables affecting teacher quality, and continue to make decisions that are informed by anecdotal evidence rather than peer-reviewed research findings.

The challenge of creating communication channels between researchers and policy makers is not a new one, yet its solution remains unclear. We suggest that a web-based portal be established to catalog research findings that address science teacher quality. The portal should be monitored by a committee of educational scholars and policy makers to ensure the quality of research. It should be easily searchable, and have the capacity to organize manuscripts based on specified criteria. We also encourage research journals in science teacher education to create criteria for publication that emphasize the discussion of research results in terms of implications for policy. We believe this will eventually benefit educational researchers as well as the dissemination of education research results.

Conclusions

Educational problems in our society are stubbornly resistant to change. Providing qualified science teachers in our nation's secondary schools has challenged Americans for over five decades. This study listened to the voices of federal and state policy makers and local school principals as they struggled to address this problem. We found that federal and state policy makers are actively creating policy, such as increasing incentives and organizing professional development, to improve science teacher quality. Yet these policy makers are challenged primarily by a lack of research based data to inform their decisions.

Principals in a community helped each other to customize federal and state policies and generate new school level policies to address their immediate needs in improving science teacher quality. In addition to an overall lack of resources, teacher union and teacher credentialing policies presented obstacles to their efforts. The findings suggest that the work of the principal and the policy maker are both necessary to the solution though neither is sufficient in and of itself. Increasing science teacher quality requires the involvement of stakeholders from both levels. Principal communities, and the use of technology to create communication channels among principals, policy makers, and science education researchers are promising mechanisms for generating effective policy at the federal, state, and school level.

Appendix

Interview questions for state/federal policy makers

1. Can you tell me some (two or three) of the significant policy discussions that you had in the last year about science and technology education?
2. What initiatives are you currently involved, or areas in which you want to be persuasive in science and technology education?
3. What were the discussions that you had last year around policy for science and technology education where you found you needed or wanted more information?
4. What information did you use to inform this discussion?
5. What information do you wish you had had?
6. What are the central questions that you have regarding science and technology education?

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