Science and Mathematics Education Centre

The Role of Administrator and Teacher Leadership in Secondary Science Education Reform

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DECLARATION

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of my knowledge and belief, this thesis contains no material previously published by any person except where due acknowledgement has been made.

Signature: 

Date: December 2014

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This dissertation is dedicated to the memory of my father, who taught me to work hard (or it's worth nothing) and to never, ever give up.

ABSTRACT

This mixed-methods study focused on the role of administrator and science teacher leadership in the context of two federally funded Math-Science Partnership (MSP) programs designed to create sustainable science education reform in the United States. In order to combine the reliability of empirical counts with the validity of lived experiences, this research included quantitative analysis of survey data and qualitative analysis of data resources through multiple levels and stages of coding. Conducted with the theoretical perspective of the structure and agency dialectic, especially as it applies to implementing reformed science teaching and leadership practice, this research focused on structures that support leadership that promotes reformed science teaching.

This study explored the impact of the MSP programs for administrators and science teachers and the persistent challenges for realizing a common vision for pedagogic change in science. Specifically, the following overarching questions guided this study: (1) How does a PD program for administrators and teachers influence administrator and teacher science leadership for reform in schools and within districts? (2) What challenges do teachers and administrators face as they try to implement science education reform? To answer these questions, I present an autoenthography and analyses of specific data focused on administrator leadership, science teacher leadership and the structures that afford or constrain this leadership practice.

The major findings of this study reveal that PD programs, like the MSP programs, lead to specific areas of growth for administrators and science teacher leaders. Specifically, I found that through participation in the MSP programs, administrators grew in their knowledge of science, how it is best taught, and their actions for supporting science teachers to implement reforms. In addition, the structures of the MSP programs empowered teachers to positive leadership action and influenced the ways they defined science teacher leadership. This study also found that collaborative action-research projects were a strategy for bridging the intervening gap between administrators and teachers in an effort to implement science education reforms. This research provides implications for building teacher leadership for science education reform via professional development and reimagined K-12 school designs for science teachers and their administrators in the United States.

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CHAPTER 1 – THE PROBLEM

> I feel like there's more that I can give. It's not that I feel like I've mastered the classroom… I'm just ready to share things on a different level…You have to feel valued in some way. (HS science teacher, interview, 2012)

I became a high school science teacher immediately after college. After my second year of teaching I had the good fortune of participating in a Math-Science Partnership (MSP) program dedicated to developing a cadre of master teachers who demonstrate intellectual engagement with scientific content, use related research-based pedagogy, and engage in leadership activities. After I completed the program, I felt that remaining a classroom science teacher limited what I could contribute to the field. Therefore, after just four short years of teaching, I left the classroom. I was seeking an experience in science education that I felt valued my knowledge, experience, and dedication to inquiry-based teaching and that would allow me to assert a broader influence on students' science learning. After I left the classroom, I transitioned to a new position as a science teacher educator in an outreach program at a university. In this role, I began to view science teaching from outside the classroom. From this perspective I was continuously reminded of the importance of the classroom teacher in the implementation of reformed science teaching that research indicated was most likely to improve college preparation, career readiness, and students' ability to make informed decisions. I began to wonder: what would keep our best science teacher leaders in the classroom? This question is the foundation of the research in this dissertation.

This longitudinal mixed-methods study was conducted in the context of two MSP programs, drawing from data over a five-year period. As a teacher-participant and graduate of one MSP program and an instructor in the other, I provide an "insider's point of view" to my analysis of participant interactions and close exploration of data sources. In this first chapter I briefly discuss the current state of science education in the United States to position the urgency of realizing science education reform. I then discuss the general challenges administrators face as they seek to lead pedagogic change in science teaching and learning. Next, I introduce the importance of developing strong science teacher leaders for implementing these reforms. I conclude by providing a brief overview of the research and structure for the dissertation.

Introduction

Although science education reform has been a topic of significant discussion since the late 1980s, progress toward these goals has been slow (AAAS, 2001; NAS, 2005; NRC, 1996; NRC, 2000). To truly make progress in this area schools must hire and retain excellent science teachers. However, teachers, like me, enter the profession only to leave for jobs in a different sector or to pursue non-teaching jobs within the education sector, such as school administrator. A few studies suggest that teacher preparation and professional development programs may be influential in stemming attrition of science teachers (Ingersoll, Merrill, & May, 2012; Loucks-Horsely, et al., 1998). In addition, research suggests that when schools give teachers autonomy and the opportunity to lead from within and beyond the classroom they are more likely to stay. Finally, the role of administrators is crucial. Studies (e.g., Nelson & Sassi, 2002; TNTP, 2012) find that when administrators get to know teachers' subject matter and how it is taught, help them access resources, and give them opportunities to grow their careers, they are likely to keep them teaching and leading at their school.

I completed this study to provide insight into the challenges and strategies for building teacher leadership for science education reform through professional development for science teachers and their administrators. This dissertation focuses on the role of administrator and science teacher leadership in the context of two MSP programs and a corresponding program for administrators designed to create sustainable science education reform, through ongoing education to science teachers and their administrators to support their understanding of science content, pedagogy, and leadership. Specifically, I examine how the program for administrators, which I refer to as the Administrators' Science Institute (ASI), influenced administrators' ability to support their science teacher leaders and how the MSP programs afforded opportunities for teachers to enact leadership practice. The involvement of administrators in the professional development focused on reformed science teaching and learning allowed me to identify persistent challenges administrators face as they attempted to support their teachers to lead efforts to implement science education reform. Additionally, I examine the roles and definitions of science teacher leader in order to provide a foundation for understanding how to better recognize teacher leadership in ways that incentivize teachers to lead from within the classroom. Finally, I identify structures that constrain science teacher leadership practice as a means for identifying new models of professional development and K-12 schools that might empower teachers to implement school-wide pedagogical change and lead efforts in science education reform. Based on the findings of the study I provide implications for developing a new framework for administrators, science teachers and teacher educators to collaboratively engage in reform efforts to improve science teaching and learning at the local level.

Science Education in the United States

Student achievement on national and international assessments can be used as evidence for the need to reform science education in the United States. The National Assessment for Educational Progress (NAEP) and the Program for International Student Assessment (PISA) measure student achievement in science content and science practices and scientific literacy, respectively. These assessments are good indicators of student knowledge and skills, as valued by reform-based curriculum, because they focus on conceptual understanding, problem solving, application of science in real-world contexts, and the ability to draw evidence-based conclusions. Student scores on the NAEP suggest that students in our schools do not have sufficient science content knowledge or an adequate understanding of scientific processes. This national data is supported by what is seen on international assessments. For example, the most recent data from the PISA reports that overall, 18% of students in the United States scored below a level 2, meaning that these students were below baseline level of proficiency necessary for effective participation in life situations related to science and technology (Fleischman, Hopstock, Pelczar, & Shelley, 2010). Compared to all 64 other countries and education systems participating in PISA, 18 had higher average scores, 33 had lower average scores, and 13 had scores not measurably different from the United States (Fleischman et al., 2010). This data shows that the United States does not score in the top 10 worldwide in scientific literacy, even though there has been some improvement. In 2006, U.S. students scored lower than the Organization for Economic Co-operation and Development (OECD) average, while in 2009, U.S. science literacy scores showed limited improvement such that they were not measurably different than the OECD average (Fleischman et al., 2010). This suggests that science education policies and reform have had only a limited impact on student achievement, and implies that there is still a significant amount of work to be done.

Since the late 1980s, these national and international assessment data have motivated educators, policymakers and community members to work to address what is referred to as the "gathering storm" through science education reform (NAS, 2005). Documents such as the National Research Council's *A Framework for K-12 Science Education*, the National Academy of Science's *Rising Above the Gathering Storm*, the *National Science Education Standards* and AAAS *Atlas of Science Literacy* were developed to address the under-performance of United States students on STEM assessments, such as NAEP and PISA (American Association for the Advancement of Science [AAAS], 2001; NAS, 2005; NRC, 2011). These recommendations for improving science education are generally referred to as reform-based science teaching, which focuses on the use of inquiry and experimentation, student-centered activities, problem solving, and open-ended questioning in an attempt to improve students' understanding and achievement in science (National Research Council, 1996). Most recently, the National Academy of Sciences released *A Framework for K-12 Science Education* which was intended to provide a broad set of expectations for students such that after graduating high school, all students will "have sufficient knowledge of science and engineering to engage in public discussions on science-related issues, be careful consumers of scientific and technical information, and enter the careers of their choice" (NAS, 2012). Reformed science education would make school science understandable, accessible, and interesting for all students in grades K–12 (Barton, 1998), leading to increased academic achievement and greater numbers of STEM professionals. Although funding agencies and foundations have dedicated significant funds to these goals, much of this funding does not make it to the science classroom (Haberman, n.d.) and progress towards these goals has been slow (Lynch, 2000). If the goal is improved understanding of science content by students and authentic application of scientific and engineering practices, then instructional practice must change to align the teaching and learning with this goal. In the section that follows, I discuss the role of science teacher education—both pre-service and in-service—in preparing and supporting high quality science teaching in order to change pedagogy in ways that improve student achievement.

Science Teacher Recruitment, Preparation and Retention

The concern about the lack of preparation of students in science has led to a focus on recruitment, preparation, retention, and on-going support of high-quality science teachers (NAS, 2005). The "gathering storm" calls to attention the importance of preparing and supporting a high quality teaching force, in order to result in better prepared students. In his State of the Union address in 2011, President Barack Obama called for an initiative to train 100,000 new teachers in mathematics, science, technology, and engineering (STEM) subjects. However, just as important as filling a teacher shortage is the concern of STEM teacher attrition (Ingersoll, 2001). Research has shown that the size of the teaching force combined with the relatively high annual turnover means that there are large flows in, through, and out of schools each year (Ingersoll, 2006). This issue is especially important in science and math teaching because unlike fields such as English, there is not a large cushion of new teachers relative to turnover, causing an overall staffing shortage (Ingersoll & May, 2010). This shortage results in an increased rate of teachers teaching out of field to cover the sciences, such that students, especially those in small rural schools or large urban schools, are being taught by under-qualified science teachers and out of field teachers (Ingersoll & May, 2010). In addition, over the past two decades, rates of mathematics and science teacher turnover have increased (Ingersoll & May, 2010). Current research on teacher attrition demonstrates that there are multiple reasons that teachers leave the profession (Borman & Dowling, 2008; Ingersoll, 2006; Ingersoll & May 2010; Ingersoll & Perda, 2010). Research has demonstrated that science teachers who are unable to implement teaching practices outside of direct instruction are more likely to suffer from "teacher burn-out" and more likely to leave teaching than those supported to engage their students in learning experiences that involve inquiry and critical thinking (Butler-Kahle, et al., 2000). Notably, science teachers are less likely to have had comprehensive pedagogical education, in terms of methods and theory courses, practice teaching, observing others, and receiving feedback on teaching (Ingersoll, Merrill, & May, 2012).

In order to address science teacher retention, teacher education programs must address some of these concerns. During Obama's State of the Union address he revealed plans to expand "promising and effective teacher preparation models" for STEM teachers, but provided little discussion about what these models would look like. The research suggests that improved teacher preparation programs would be inquiry-based, extend over a long period of time, and be embedded within the teaching context. In addition, these programs would focus on content knowledge acquisition and pedagogy aligned with reformed science teaching. However, pre-service education is not enough to address the significant shifts required by frameworks on national science education reform. To ensure adequate preparation and support for implementing reforms, teachers must remain learners after leaving teacher preparation programs through professional development. In-service professional development is key for developing science teachers in ways that prepare them to excel as science teachers. I decided to focus my dissertation on the influence of professional development in the form of MSP programs of which I was a part in order to see how these programs, focused on content, pedagogy, and leadership, influence teacher practice. In the following section, I discuss research on teacher professional development in order to situate this research.

Professional Development

There is growing evidence that high-quality teaching significantly impacts the academic achievement of students (Borko, 2004). Professional development accounts for much of the efforts intended to improve science teaching and learning for in-service teachers. Policy makers, district leaders and educational scholars advocate for content-based professional development for science teachers in order to prepare a college and workforce ready student population. Furthermore, studies suggest that professional development programs may be influential in stemming attrition of K-12 science teachers (Ingersoll, Merrill, & May, 2012) and supporting science teachers to refocus their K-12 teaching in order to improve college preparation, STEM career readiness, and students' ability to make informed decisions (Loucks-Horsley, et al., 1998). Especially because science teachers are less likely to have had comprehensive pedagogical education, in terms of methods and theory courses, practice teaching, observing others, and receiving feedback on teaching (Ingersoll, Merrill, & May, 2012), in-service professional development is key for developing science teachers in ways that prepare them to excel as science teachers.

Often, teacher professional development programs are too short-lived to foster change in teacher classroom practice (Hawley & Valli, 1999; Huberman, 1997). Research highlights some important features that characterize effective professional development programs. According to Harrison and colleagues (2008), effective professional development programs are long-term, include context-specific inquiries into teaching and learning, emphasize reflection and discussion with peers, and provide content-specific learning experiences. In addition, effective professional development programs are grounded in the importance of subject matter knowledge, pedagogical content knowledge, and the "scholarship of teaching," which refers to improving teaching through reflection and professional discourse with others (Hutchings & Shulman, 1999; Loucks-Horsely, Stiles & Hewson, 1996; Shulman, 1987). Subject matter knowledge or content knowledge refers to the facts, concepts and processes within the discipline, such as chemistry. Pedagogical content knowledge, articulated by Shulman (1987), refers to the teaching and learning of the discipline, including the knowledge of how students learn and the specific challenges of teaching within that discipline. The scholarship of teaching is concerned with the ways in which teachers articulate how they teach and why, specifically as it relates to the ways in which it can inform the learning of other teachers and leaders (Hutchings & Shulman, 1999). The scholarship of teaching makes teaching practices public in a way that encourages discourse and enhances leadership potential of teachers.

Evidence suggests that we might consider teacher professional development policies in countries whose students outperform the U.S. in order to identify areas to change. Notably, in countries that have consistently high rankings on the PISA and TIMSS—Finland, Korea, Singapore, Japan and the United Kingdom—support for teachers and teacher learning is a top priority. These nations provide strong pre-service teacher education, extensive opportunities for formal and informal professional development embedded in teachers' contexts, time for professional learning in addition to having policies and practices in place that promote and support teacher leadership as a means to improve instructional practice (Wei, Darling-Hammond, Andree, Richardson, & Orphanos, 2009; Stigler & Hiebert, 1999). In these countries, teacher leadership involves collaboration, sharing of practice, leading from the classroom, and collective responsibility for the success of students (Wei, Darling-Hammond, Andree, Richardson, & Orphanos, 2009). Within this framework, teachers and traditional leaders would collaboratively focus on the vision for science education and work together to attain it. This research has implications for changing school systems and improving student outcomes through innovatively designed professional development programs.

Given this research, a promising strategy in the U.S. for the professional development of science teachers are the National Science Foundation (NSF) MSP programs. MSP programs seek to reform math and science by building capacity and integrating the role of higher education with that of K-12 education. MSP programs fund research and development efforts that support innovative partnerships to improve K-12 student achievement in math and science. MSP programs focus on reducing achievement gaps in the math and science performance of diverse student populations. Partnerships between institutions of higher education and K-12 districts are created to effect deep, lasting improvement. MSP programs have 5 key features, (1) partnership-driven; (2) teacher quality, quantity and diversity' (3) challenging courses and curricula; (4) evidence-based design and outcomes; and (5) institutional change and sustainability. One specific program of MSPs is focused on meeting national needs for teacher leaders/master teachers who have a deep knowledge of disciplinary content for teaching and are fully prepared to be school- or district-based intellectual leaders in math or science. Since leadership is a powerful lever for promoting reform, these programs provide the important link between science teaching and leadership practice. Understanding the design of these programs is important, because this research takes place within two such MSP programs. In the section that follows I discuss the role of administrator and teacher leadership in science education reform.

Leadership

As we move into a new era of reform for science education, we must focus on the role that leadership plays in facilitating these reforms. In the United States, education is decentralized such that the power over education is given to states and local authorities, as well as to individual schools and higher education institutions (USDOE, 2008). However, despite education decentralization, the federal government does provide policy leadership and provide assistance in support of education throughout the nation (e.g., No Child Left Behind, Race to the Top). The individual school is the competent authority in the United States for nearly all academic matters (USDOE, 2008). In the US, there are nearly 130,000 individual institutions in the U.S. education system, including 117,000 primary and secondary schools (USDOE, 2008). These institutions vary widely in governance arrangements. However, the typical school system is structured with a district level administration, including a superintendent and various instructional supervisors. Individual schools are structured with a building principal who is intended to both manage the operations of the school building as well as supervise instruction across all content areas. In the section that follows I discuss the role of these administrators in facilitating science education reform through pedagogic leadership that supports and empowers teachers to teach inquiry-based science and lead school-wide change.

Administrator leadership. Within the field of educational leadership, research points to the significant role that district and building-level administrators play in facilitating change in teacher practice and school culture (Fullan, 2008; Hopkins, Ainscow, & West, 1994; Lewthwaite, 2006; Spillane, 2008). Research around school culture and leadership supports the connection between administrative support and teacher success, finding that the degree to which any innovation is successfully integrated into a school culture is connected to the actions of school administrators in supporting these innovations (Fullan, 1992; Hall & Hord, 1987; Supovitz, et al., 2000). Indeed, several studies have found that, when colleagues, parents, and administrators do not support reform measures, classroom teachers often find it difficult to sustain changes in their teaching practices (Jeanpierre, Oberhauser, & Freeman, 2005; Martin, 2006). Thus, the extent to which teachers are supported to implement reform science teaching practices is dependent upon the administrative practices of district and building-level decision-makers, including superintendents, principals and vice-principals, science supervisors/curriculum leaders, and science department chairs. However, despite this important responsibility, the science classroom that administrators expect and that which teachers of reform-based science aim to create are disparate (Chrispeels, Burke, Johnson & Daly, 2008).

Some research suggests that this division is related to the inconsistencies between what is being managed (the teaching and learning of students) and the managerial practices of the building administrators (Nelson & Sassi, 2000a). The present conceptualization of administrative supervision is inadequate because it separates consideration of the pedagogical process from the disciplinary subject being taught. This becomes particularly important because administrators' ideas about learning and teaching in their content area affect administrative practice itself (Nelson & Sassi, 2000a). When administrators are more familiar with the ways in which students best learn in a specific content area, a significant pedagogical advantage emerges (Nelson & Sassi, 2000b; Stein & Nelson, 2003). Specifically, administrators, including curriculum personnel and building principals, might consider reform-based curriculum as an option for their schools and more effectively guide pedagogy at the classroom level. Therefore, expanding administrative understanding of content and reform teaching methods could enable administrators to better support teachers and students in K–12 science and pedagogic leadership in their schools, especially in relationship to the personal agency of teachers to lead these reforms.

Research supports the idea that supervision and evaluation of teachers by building administrators influence a teacher's ability to implement reform-based teaching practices (Howe & Stubbs, 2001; Nelson & Sassi, 2000a). While approximately 98% of principals were teachers first, it is unlikely that they have experience teaching across multiple grade levels and content areas. The data show that only 11% of all public school teachers are science teachers so assuming science teachers become principals at the same rate as other teachers, we can conclude that about 90% of all principals are not science content specialists, and their administrative coursework likely did not focus on understanding and supporting inquiry practices in K–12 science classrooms (Levine, 2005). This point is salient because classrooms in which teachers are working to implement reform-based teaching can look very different from traditional classrooms. Administrators might neither recognize this nor understand the practices that these teachers use and why they choose to use them. In current science education reform efforts, both the ideas in a subject and the ways in which students and teachers work with them matter (National Science Foundation [NSF], 2010; Shulman, 2000). These observations forefront the issue of principals' pedagogical content knowledge as it relates to science (Stein & Nelson, 2003). Rather than simply looking at a checklist of teacher behaviors as good instruction, administrators will need to focus on how these elements are used to support the development of subject-related thinking (Nelson & Sassi, 2000b). This means that most of the knowledge required for improving teaching and learning in schools resides in the teachers who deliver instruction, rather than the administrators that manage them (Elmore, 2000; York-Barr & Duke, 2004). Therefore, in addition to considering the ability of administrators to recognize and support inquiry-based teaching, administrators must also find ways to empower teachers to become experts in their content, innovative in their pedagogy and confident in their abilities as leaders in order to realize science education reform. In the next section, I discuss teacher leadership as a strategy for both leading school change as well as for retaining our best science teachers.

Teacher leadership. Teacher leadership is a necessary component of effectively implementing reformed teaching practices and retaining high quality teachers (Fullan, 2005; Howe & Stubbs, 2001; Silva et al., 2000). Teacher leadership, which is typically separate from instructional leadership, emerged in schools and districts over the past few decades as a means of addressing the isolated nature of teaching and the desire to increase teacher status (York-Barr & Duke, 2004). The concept of teacher leadership came to fruition in schools with school accountability (the process of evaluating school performance on the basis of student performance measures) as teacher leadership was seen as a way to improve teaching (Smylie, Conley, & Marks, 2002). While encouraging teacher leaders to accelerate changes in instruction can be empowering for teachers, it may also serve to meet the needs of administrators under pressure from external accountability measures. For example, a science teacher may focus on improving science teaching and learning in their classroom, while she is simultaneously encouraged by her administrator to lead changes in instruction that lead to increased student test scores. This is problematic because although it appears to be facilitating teacher leadership practice, it doesn't necessarily promote a model of teacher leadership that is likely to keep them teaching and leading at their school (TNTP, 2102).

Although there is little consensus around what constitutes "teacher leadership," it tends to encompass a range of activities: teacher leaders promote changes in instruction, take on administrative duties, or hold a formal leadership role (Neumerski, 2013). Teacher leaders can be consultants, curriculum managers, department chairs, mentor teachers, professional development coordinators, resource teachers, specialists, coaches, and demonstration teachers (Mangin & Stoelinga, 2008). In literature and policy, teacher leaders are often out of the classroom full-time, although some teacher leaders assume leadership tasks in addition to full-time teaching or less often, combine part-time teaching and part-time leadership (York-Barr & Duke, 2004). Teacher leaders have pedagogical content expertise and provide formal and/or informal support to their colleagues in changing instructional practice in their building. Teacher leaders individually or collectively influence members of their school communities in order to improve teaching and learning practices in an attempt to increase student achievement (Ritchie, in press). These teacher leaders are risk-takers and innovators within their classrooms who coordinate and collaborate with colleagues in discussing problems, sharing teaching and learning approaches, and actively exploring ways of overcoming structural constraints which impede the best teaching and learning environments for their students (Silva et al., 2000). Teacher leaders are linked to deliberate and sustained school reform and are instrumental in the advancement of reform teaching practices in schools (Crowther, Ferguson, & Hann, 2009). Given these findings, it is likely that science teacher leaders play a crucial role in promoting science education reform.

The role of science teacher leaders is critical when examining how reformed teaching practices can be integrated system wide and not merely in a few distinct classrooms. These science teacher leaders focus on the essential elements of science education reform, such as aligning curriculum, instruction, and assessment with national, state and local standards; implementing professional development based on district and state needs and ensuring that the infrastructure needed to sustain the science program is firmly in place (NSTA, 2003). Recent calls for teacher leadership suggest that leadership positions be a part of teachers' daily work (Fullan, 2008; Silva et al., 2000). This conceptualization of teacher leadership focuses on empowering teacher leaders to collaborate with other teachers, discuss common problems, share approaches to learning, and explore ways to overcome structural constraints (Silva et al., 2000). This ability to form collective projects and persuade the activities of others is related to the profoundly social nature of agency. Thus for science teachers to become effective leaders, administrators must create a culture which makes room for them to meaningfully participate in important conversations about science teaching and learning, with all stakeholders, in a professional setting (Silva et al., 2000). This culture can be one of distributed leadership, coparticipation, mutual respect, and shared responsibility. In order to build capacity for distributed leadership in science education, we need both formal and informal leaders to have the knowledge of science and how science is learned so that they can build a culture of professional learning based on teaching and learning science. Additionally, administrators need to foster a professional learning culture centered on collaboration and ongoing improvements aimed at supporting reformed science teaching. In the section that follows I highlight what administrators can do to support science teacher leadership.

Supporting capacity for science teacher leadership. When the school culture does not support the learning of science, neither administrators nor teachers recognize the potential of what they can do as a foundation for implementing science education reform. In these situations, teachers advocating reform curriculum often work in an environment where they are "always playing by the rules" and therefore feel like they are "infringing on [administrator] territory" when they try to take initiative (Silva et al., 2000, p. 446). The difficulties teachers face in exercising effective leadership contribute to attrition from the teaching profession, especially when teachers are unable to conform and play the rules of the game (Silva et al., 2000). The lack of alignment between administrators and science teachers, results in teachers feeling powerless and administrators struggling to recruit, develop and retain excellent teachers over time. Therefore, empowering teachers to participate in decision-making processes within schools and exercise agency can be a means to address the apparent science teacher shortage, encourage science education reform and support teacher leadership (Leithwood & Jantzi, 2000; TNTP, 2012).

One way to build capacity for teacher leadership is to focus on building a culture of distributed leadership. Distributed leadership, the practice of developing leadership teams and professional learning communities (Spillane & Diamond, 2007), can be a means for empowering teachers. Research suggests that, in addition to the principal, many other stakeholders are involved in leading and managing instruction (Spillane & Diamond, 2007). Distributed leadership focuses on leadership as an organizational quality that reaches beyond formal leaders to informal leaders as well (Spillane, Diamond, Walker, Halverson & Jita, 2001). In districts that support distributed leadership, teachers are provided an opportunity to have a voice in formulating the vision for change that will occur in their own classrooms (Roth, 2007; Spillane & Diamond, 1997). Leadership practices of principals, assistant principals, mentor teachers, department chairs, and other teachers all contribute to our understanding the ways in which curriculum is enacted in the classroom (Spillane & Diamond, 2007).

This section focused on the role of leadership in science education reform. Research suggests that leaders – both administrators and teachers – must have an understanding of science content and leadership practice in order to implement reforms. Given the importance of science content and leadership in implementing science education reform, it is important to consider how professional development focused on administrator and teacher leadership might address this need. In the next section I propose a model of professional development for addressing the implications from the literature.

PD for Administrators and Teacher Leaders

Opportunities for participation by teachers and administrators in effective professional development are necessary for increasing pedagogical content knowledge and enhancing understanding of science education reform. Effective professional development must address pedagogical content knowledge, beliefs about teaching and learning, the understanding of science education reform, and development of leadership capacity of both teachers and administrators, which ultimately impact the teaching and learning of science and the academic achievement of students. Figure 1 depicts a model for effective professional development that builds on the National Science Education Standards for professional development (NRC, 1996).

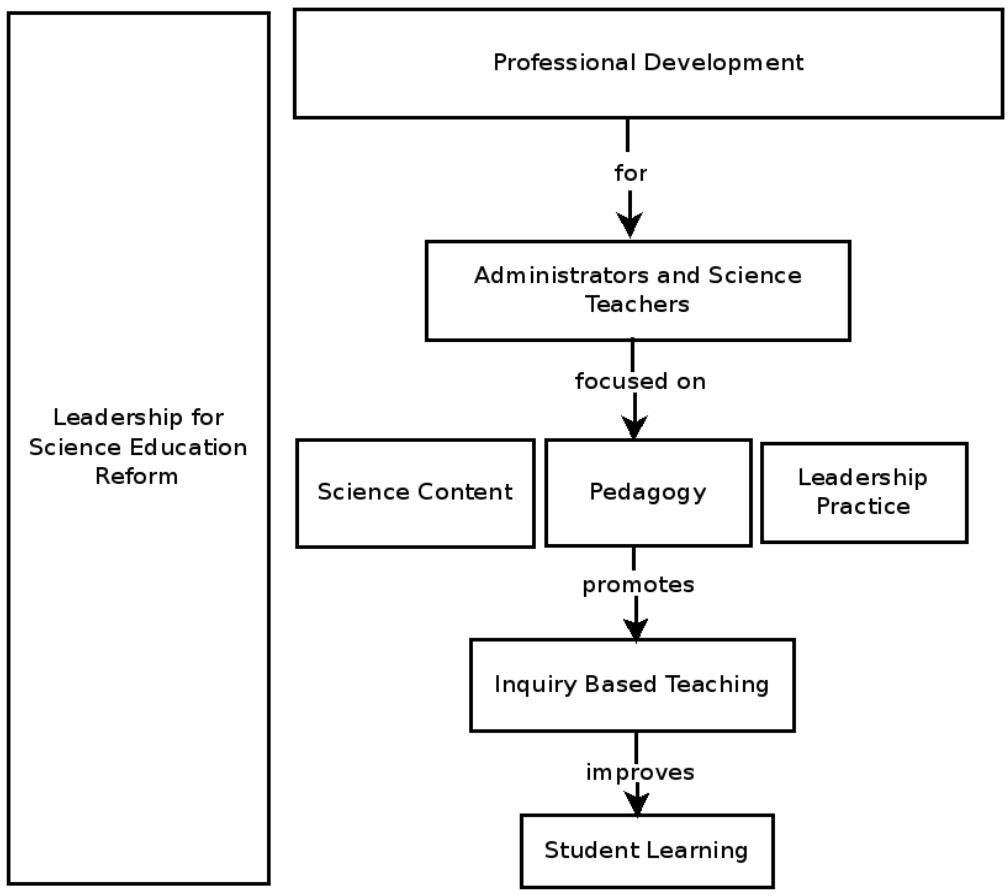

Figure 1. Model for professional development aimed to enhance leadership for science education reform.

In this model, administrators are included not only as providers of professional development for science teachers, but also as participants with teachers in science specific professional development programs for science education reform.

This dissertation focuses on two MSP programs, one at a university in the Northeast which I refer to as the Northeast Science Teacher Program (NSTP) program and the paired administrator program (ASI), as well as an MSP program at a university in the Midwest, which I refer to as the Institute for Biology Teachers (IBT). These MSP programs serve as specific examples of this model of professional development in order to illuminate positive outcomes of the experience and draw attention to persistent challenges. The research questions in this dissertation serve to focus a line of inquiry that builds knowledge, which informs thoughtful designs of professional development for science teacher leaders and administrators to work together to realize science education reform.

Purpose of the Study

Although a significant amount of research exists about teacher leadership, administrators, and professional development, in general, it does not focus on professional development programs dedicated to building science leadership by teachers and their administrators. This dissertation seeks to fill the gap in the literature. The role of science teacher and administrator leadership in supporting the reform of science teaching in K–12 schools is not well documented, especially at the secondary school level. To fill this void I present findings from a five-year longitudinal study of teacher and administrator participants in two federally funded MSP programs. My conceptual and methodological framework is grounded on theoretical underpinnings in cultural sociology. Specifically, I draw from William Sewell's (1992; 1999) work to make sense of the ways in which structures encourage or constrain teachers and administrator to meet their goals. Additionally, I draw on the framework of transformational leadership to highlight pedagogic leadership at multiple levels, paying particular attention to the roles and definitions of teacher leader in the context of school science. Furthermore, I draw on the theories of pedagogic leadership and leadership content knowledge to better understand the role of administrators in supporting the implementation of science education reform. Specifically, this research explores the impact of the paired professional development program for administrators and teachers as a means for realizing a common vision for pedagogic change in science. I discuss theoretical frameworks and methodological considerations for this research in detail in Chapter 3.

General Questions

The overall research questions that guided this study and the chapters in which these questions are addressed are below:

1) How does a PD program for administrators and teachers influence administrator and teacher science leadership for reform in schools and within districts?
    a. Who am I in relation to this research study? (Ch. 3)
    b. What impact does a PD program for administrators have on administrators' leadership content knowledge and pedagogic leadership with regards to science teaching and learning? (Ch. 4)
    c. What leadership roles do science teachers play in their classroom, schools, districts, and nationally? (Ch. 5)
    d. What structures support or hinder teacher agency as science teacher leaders? (Ch. 6)
2) What challenges do teachers and administrators face as they try to implement science education reform?
    a. Who am I in relation to this research study? (Ch. 3)
    b. What challenges do administrators face in supporting science teaching and learning? (Ch. 4)
    c. How do teachers define science teacher leadership? (Ch. 5)
    d. What structures support or hinder teacher agency as science teacher leaders? (Ch. 6)

Research Design

To answer these questions, I employ a mixed methods research design. Using a multiphase design I employ both quantitative analysis of data from validated survey instruments and qualitative analyses of administrators' and teachers' experiences within the context of their involvement within the MSP programs. In this study, quantitative survey data precedes the qualitative work. Through an interpretive research paradigm I provide a detailed, descriptive account of the knowledge and actions of science teacher and administrator participants throughout participation in the programs. As a former teacher participant in one of the MSP programs and an instructor in the other, I bring an "insider's point of view" to my analysis of participant interactions and my close exploration of several sources of data from which I identify critical categories and emergent meanings. In the sections that follow I provide a brief summary of the context and participants in the study. I also include an overview of the data sources and analytical approach. A more detailed description of the research design is included in Chapter 3.

Context of the Study

This research takes place in the context of two MSP programs. The first MSP, the NSTP was a collaborative initiative between a private, northeastern university's chemistry department and school of education, focused on providing in-service teachers with content knowledge, science education theory and model instructional strategies in order to encourage teachers to implement reform-based teaching practices in their classrooms. Another outcome expected by program administrators was that the graduates would become teacher leaders in their schools and/or districts (Blasie & Kahle, 2009). The NSTP also includes the ASI focused on developing the capacity of science teachers' administrators for supporting science education reform. MSP 2, the Institute for Biology Teachers (IBT), is a program at a university in the Midwest. The IBT is a collaboration between the university and the local zoo, science center, and other field trip sites aimed at enhancing content knowledge and pedagogy, through a blend of life sciences research and content and science education research and methods. Similar to the NSTP, this program also aims to develop science teacher leaders.

Participants

The participants in this study were 186 secondary science teachers who participated in the MSP programs from 2005-2011 and 54 school and district leaders who participated in ASI from 2005-2009. Participating teachers were from large suburban school districts and city school districts in equal numbers, with a very small number from rural districts. NSTP enrolled teachers from the region around a large northeastern city while IBT enrolled a national cohort from across the United States. Administrator participants included building principals, science department chairs, district level supervisors and curriculum coordinators, and assistant principals.

Data Collection and Analyses

I conducted the research through an initial quantitative analysis of surveys of administrator and teacher participants from throughout their participation in the MSP programs. I followed up the quantitative analysis using qualitative data, including a large volume of documentary evidence—journal entries, electronic portfolios, essays and documents evaluating the effectiveness of the MSP programs—to further explore the themes identified in the first stages of the research. I used multiple stages and levels of coding through a qualitative computer program in order to uncover and explore themes that emerge from the quantitative analysis. Validity of the analysis was improved through triangulation of the data sources. Specific pieces of data were selected to answer chapter-specific questions and are further explained within individual chapters. In addition, a more detailed discussion of the research methodologies, setting for the research, sources of data and analytical approaches appear in the third chapter.

Overview of the Dissertation

This dissertation is written manuscript style. This means that rather than write the entire dissertation in a traditional "book" format, instead, I have prepared chapters 4, 5, and 6 as manuscript style papers to be submitted to a journal for peer-review. For this reason, these chapters are formatted to read as individual manuscripts rather than as book chapters. This means that these three data chapters contain information that may be repetitive in the context of the whole dissertation (i.e., these chapters each discuss the context of the study, the theory, and methods, etc.). The justification for preparing the data chapters in a non-traditional format is supported by a recent movement in higher education that seeks to rethink the dissertation in order to prepare a document that is much more applicable to the broader public (Patton, 2013). By preparing the dissertation manuscript style, the dissertation can be more easily edited as three or four publishable articles, instead of one book-length text (Germano, 2013). Supporters of this approach suggest that this style of dissertation better prepares graduates for employment by setting them up for success through strategic submission to journals (Patton, 2013). In the section that follows I provide an overview of each of the chapters of the dissertation.

Chapter One

In this first chapter, I have offered an overview of the factors contributing to the slow progress toward science education reform. Science education reform efforts stem from national policy documents and federal legislation, attempting to address low student achievement in science based on national and international achievement data. Despite the attempts to address this problem, these policy documents have had only a minor impact on student achievement. Extensive research points to the role of the teacher as having the greatest impact on achievement, but recruiting, preparing, retaining and supporting excellent science teachers continues to be a problem. Professional development for teachers is used as a means to address teacher preparation, but is incomplete when it does not take into account the role of administrators and school context. The knowledge and practices of administrators have an impact on the empowerment and support of teachers to lead efforts in science education reform. Throughout this chapter, I made reference to several sociocultural frameworks, which I will use to explore this problem. Questions for inquiry were established that focus on these particular issues within the context of MSP programs for secondary science teachers and their administrators.

Chapter Two

Chapter two is an autoethnographical account of my journey towards becoming a teacher and coming to write this dissertation. This chapter offers foundational information about my own life experiences. I use autoethnography as both a process and a product, in order to overcome epistemological problems raised by the perspectives that I bring to the research. In this chapter, I retrospectively and selectively present and analyze vignettes that draw attention to the specific issues in this dissertation in order to acknowledge and accommodate my influence on the research itself. I begin by examining my path to becoming a science teacher and use a sociocultural lens to examine the role of emotions in this journey. In addition, I use the theory of structure and agency to examine my classroom teaching experience and consider the ways in which structures, including those embedded in the MSP program and in my school context, influenced my agency and ultimately my decision to leave the classroom. Finally, I consider my role as a science leader using the lens of transformational leadership. I conclude the chapter by discussing how this autoethnography informs and contributes to the dissertation.

Chapter Three

The third chapter describes the methodological framework for the study. I make a case for using a mixed methods approach and describe the importance of the autoethnographical chapter for situating myself in the context of the research. In addition, I describe the philosophical assumptions that guided my research. The manuscript style dissertation requires that some theoretical frameworks are more useful for analyzing particular research questions and therefore I discuss theoretical frames in each chapter. However in this chapter, I describe the overarching theoretical perspectives that focus my analysis. Finally, I explain the multiphase design used to answer the chapter-specific questions through quantitative and qualitative analysis of the data sources. I include an overview of the context, participants, and data sources in order to summarize methodological considerations within each chapter.

Chapter Four

Chapter four is the first chapter prepared manuscript style. In this chapter I share findings from the ASI about the influence of the participation in the ASI on administrators' content-specific leadership necessary for supporting reform science teaching. I also highlight challenges that emerged as administrators participated in the professional development. I use a three-phased mixed methods design where an initial quantitative analysis of survey data highlights areas of growth and a subsequent qualitative analysis, using the lens of reformed science leadership, further supports these claims and provides an in depth view of challenges administrators face. I summarize findings, which point to the need for discipline-specific professional development programs for building administrator leadership content knowledge in ways that allow them to enact credible knowledge of teaching and learning to support and empower their science teachers in pedagogical change. This chapter also highlights challenges outside the scope of the ASI and includes recommendations for designing context-specific, embedded professional development for science teachers and their administrators as a key strategy for helping administrators to support effective science teaching aligned with the vision of reformed science education.

Chapter Five

The purpose of chapter five is to better understand how science teachers engaged in the two MSP programs define and engage in teacher leadership practice. Quantitative analysis of survey data provides the foundation for building descriptive profiles of science teacher leaders and the qualitative analysis of interviews, electronic portfolios and leadership essays explores science teachers' roles and definitions of teacher leadership. To categorize and analyze roles of teacher leadership, I use the dimensions of leadership practice (DLP) as a conceptual framework and subsequently apply the lens of transformational science leadership to describe how teachers make meaning around teacher leadership practice. I share findings that suggest science teachers see leadership roles that are externally validated as more legitimate than others and tend to define science leadership as something outside their daily work, based on leading and managing others. I present implications for how school context can contribute to roles and definitions of science teacher leadership, which can translate to transformative action by science teachers leading from within their classrooms.

Chapter Six

The research in chapter six seeks to uncover the hindrances and affordances to science teacher leadership practice in order to better understand how to support science teacher leaders to lead from the classroom. In this chapter, I exclusively use qualitative analysis through coding of multiple sources of data to highlight structures that hinder and afford science teacher leadership practice (agency). Findings highlight specific examples of structures—both schema and resources—that contribute to the ability of teachers to enact agency in their own field. Findings suggest that PD programs and school context influence the ability of science teacher leaders to enact leadership practices within their schools. I conclude this chapter with implications for the ways that schools are designed to support and nurture science teacher leadership in order to build a space for happier and healthier professionals. I suggest that programs that seek to develop science teacher leaders should consider the school context of teachers and schools that seek to keep high quality science teacher leading from within the classroom need to consider school-based models of teacher leadership.

Chapter Seven

In chapter seven I synthesize findings and provide implications of this study in relation to the overall research questions.

Conclusions

Science education reform is the focus of many important federal initiatives as the United States seeks to increase science literacy of all students. In order to realize this goal, the quality of science teaching must be addressed. While, teachers enter the profession through multiple pathways, professional development, administrator support and other on-the-job learning enable teachers to realize their potential, in turn improving the teaching and learning in their classrooms. However, while many teachers seek out professional development opportunities, some are successful at implementing them in their classrooms while for others, their efforts are truncated by a lack of understanding and support by their administrators.

Developing a new framework that engages administrators and teachers in reform efforts is necessary to improve science teaching and learning. The experiences of secondary science teachers in a professional development program aimed at strengthening and reforming science education can make explicit the structures that contribute to the transformation of science teachers and their classroom practices. By focusing on their relationship with their administrators and the independent knowledge, perception and experiences of their administrators, another essential layer of science education reform can be elucidated. This dissertation serves to represent the interactions at the intersection between science teachers, building administrators and professional development and explore the ways in which structures promote or truncate science education reform. Additionally, it seeks to determine how a professional development program focused on content knowledge, pedagogical practices and teacher leadership impacts teacher practice. Exposing the different schemas and access to resources that contribute to the differential affordance of teacher agency can inform administrators, policy makers, and science teacher educators as they develop programs and structures that contribute to reform-based science teaching and retention of excellent science teachers.

CHAPTER 2 – MY LIFE AS A SCIENCE EDUCATOR: AN AUTOETHNOGRAPHY

> The stories ethnographers create are as much a reflection of their own cultural positioning as they are descriptions of the positioning of others. Making these historically-constituted positions clear to the reader, that is, writing autobiography is one way of understanding and incorporating our prejudices into our practices and into what we produce. Making sense and use of representations of some Other involves our own positioning in relation to what we are seeing as much as any meaning inherent in the images themselves; autobiography is one of the central means of making this positioning salient. (Roth, 2000, p. 7)

In the above citation, Wolf-Michael Roth (2000) describes the importance of autobiographical narratives for constructing knowledge and stabilizing subjectivity. Doing a study situated within Math-Science Partnership programs of which I was a part, is challenging. In order to overcome epistemological problems raised by the perspectives that I bring to the research, I use autoethnography to recollect the lived experiences that have shaped my life and share these with the reader (Eisner, 1997). In this way, I embody the knowledge brought forward by this research such that I forefront "understanding the Self to understand the Other" (Roth, 2000). This approach offers a strategy for bringing an "insider's point of view" to my analyses and working through epistemological challenges inherent in studying a program in which I participated. In Chapter 3 I provide a more in-depth view of these issues methodologically and theoretically. In this chapter, I seek to critically analyze my journey in the sciences and in science education that has influenced the way that I teach, learn and do science and the ways in which I am positioned to make meaning from data. In addition, I draw on my experiences with education, generally, and science education, specifically to situate my research. As such, I aim to promote coherence among scientific knowledge of self, understanding of science education and experiences in the world by drawing on this first-person methodology.

Introduction

As I look back at my life history, becoming a science educator was not necessarily something that I sought out, rather my journey shaped my life and destiny in ways that led me to teaching. In order to understand my experiences, I highlight pivotal moments from my life to provide insight into the self (Settelmaier & Taylor, 2001). In this chapter, my personal experiences and emotions constitute the data to be analyzed. I describe my lived experiences in order to develop an understanding of my place in the social and material world. I focus on my own personal trajectory towards teaching via an alternative teacher certification program and I examine my experiences in a professional development program for secondary science teachers. The focus in this chapter is on exploring these experiences and interpreting my relationship with science teaching and learning over time in an attempt to make sense of how my own experiences, especially with regards to opportunities for leadership, have ultimately led me to leave the classroom and to assume my current position as a science educator with Washington University's Institute for School Partnership.

In this chapter I examine lived vignettes that shaped my growth as an educator in the sciences and related to the content of this dissertation. These vignettes inform the way that I see science education reform and the perspective I bring to this work. In this chapter I explore four overarching topics: (1) coming to science teaching; (2) the role of science content and pedagogy in science teaching; (3) professional development for science education reform; and (4) science leadership (by administrators and teachers). First, I begin by telling the story of how my personal life and school life brought me to teaching. Second, I examine my work as a teacher and connect this experience to my understanding of science content and pedagogy. Next, I describe my experience in a professional development institute for science teachers, which allowed me to understand teaching and learning in new ways and ultimately changed my course from classroom teaching to that of a science educator and researcher. Finally, I analyze a vignette representing the most recent five years of my career in order to connect my experience to the more general discussion of science teacher leadership practice and science teacher retention. I conclude this chapter by discussing the impact of these experiences on my work as a science teacher educator. Focusing on my experiences as someone who has left classroom teaching, but who remains in science education, is salient to the themes I examine in subsequent chapters in this dissertation.

Methodological and Theoretical Framework

After my first two years of teaching, I enrolled in a master's degree program for in-service science teachers. In my coursework related to the teaching and learning of chemistry, we were encouraged to explore sociocultural perspectives (e.g., Sewell, 1999; Vygotsky, 1978) and view our classroom teaching using this lens. In my autoethnography (Roth, 2000), I continue to use sociocultural theories as a lens for understanding teaching and learning. Throughout this chapter, I draw from memories and other artifacts to recall and reflect on my experiences in the context of these theories. This process of reflecting on my experiences has advanced my work as a researcher in this area and influenced the questions for my research. In the section that follows I offer a brief discussion of autoethnography and the theories that frame my analyses. I examine these theories and methodologies more thoroughly in Chapter 3.

Autoethnography is both a process and a product (Ellis, 2004). Autoethnography as a process provides a way to concentrate on producing meaningful and accessible research grounded in personal experience (Ellis & Bochner, 2000). As a researcher, I do autoethnography by retrospectively and selectively presenting and analyzing vignettes that stem from being part of the culture of the NSTP. Through the process of autoethnography, I produce this autoethnographical chapter as a part of my dissertation in order to acknowledge and accommodate my influence on who, what, where, when and how I completed this research. To do this, I present vignettes that support four themes that became salient as I formulated the questions I ask in this dissertation. These vignettes from my life are shared in order to draw attention to the specific issues that are relevant to the dissertation focused on teacher and administrator leadership for science education reform. The autoethnography illustrates critical categories and emergent meanings developed by comparing and contrasting my personal experience against existing research and examining relevant cultural artifacts (Ellis, 2004). The theories that framed my analyses in Chapters 4, 5, and 6, were drawn on in order to present and analyze each vignette.

Using a layered account I focus on my experience alongside data analysis and relevant literature. I select vignettes, collect and share data around the vignettes, and analyze this data to frame my research and share how my experiences influenced the experience of doing and writing this research. To focus the autoethnography, I use distinct theories as lenses for making meaning of my lived experiences. I first use sociocultural theories to investigate the role of emotions in supporting me in becoming a teacher and to examine structure and agency of my experience as a Teach for America teacher in Camden. I then bring in transformational leadership as I consider the influence of my professional development experience. I use each of these theories independently in order to connect my experiences to existing knowledge and frame the research of my dissertation.

Teaching is emotional work. Drawing on interactive ritual (IR) theory (Collins, 2004) research suggests that positive emotional energy can be achieved through successful interaction chains reproduced in teachers' classrooms (Ritchie, Tobin, Roth, & Carambo, 2007). I draw on this theory as I present vignettes of my own teaching experience and analyze the role of emotions. I then draw on the theory of structure and agency (Sewell, 1992) to analyze the influence of professional development, administrators, and school structures on science teacher leadership practice. Structure and agency are dialectically related, such that structures influence agency, and agency can lead to transformation in structures. Actions can sustain reproduction of structures as well as make transformation possible. Therefore, transformational teacher leadership practice can be considered a specific representation of agency. Furthermore, I introduce the frameworks of leadership content knowledge and pedagogic leadership to support my focus on the goals of science education reform, including scientific and technological literacy, improved approaches for achieving equity for all students, and better preparation of students for careers in the modern workforce (NAS, 2012). Pedagogic leadership focuses on the cultural, moral and societal aspects of what is learned and why it is learned (MacNeill, Cavanagh, & Silcox, 2005) while leadership content knowledge is focused on knowledge of the subject matter instruction regarding how it is best taught and learned (Stein & Nelson, 2003). These theoretical frameworks were used to both select vignettes as well as to analyze these experiences in order to connect them to the questions raised in this dissertation.

Coming to Science Teaching

My Early Science Education

In this section I discuss my experiences with science and teaching, both in school and outside of school, to paint a picture of how I came to be a science teacher.

I present vignettes of my lived experience and use the framework of emotional energy to analyze these experiences.

My experiences in K-12 school. I believe that my school experiences had a large impact on my love of science, but an even larger impact on my love of learning and my path to a career in education. Throughout my life I had many influential teachers, however, two teachers truly impacted the direction of my life. In elementary school, my fifth grade teacher encouraged all of us to love science. In fact, being in his class was like watching an episode of Mr. Wizard.[1] Looking back on my fifth grade experience, I know that Mr. Nagel was an excellent teacher. He was able to tap into our natural curiosity in order to lead us to inquire about the world around us and, in turn, learn science. It was because of my teacher that I became interested in science. This lived experience is backed up by research that indicates that teachers make an important difference to student learning (Rowan, Correnti, & Miller, 2002). It was with Mr. Nagel that I completed my first science project. I was able to test the effects of different liquids on teeth and I even made sure that I had a control! When my experiment yielded results, I felt a sense of satisfaction. This was such an interesting discipline, full of so many possibilities.

However, despite my academic achievement in science and my mastery of the content as indicated by the grade on my project, one of the most indelible memories of the experiences are the emotions that accompanied my accomplishments. Teaching and learning are emotional endeavors. Understanding emotions is an important part of the learning experience. The ways that teachers and students emotionally interact in the classroom contributes to the success in engaging in the relevant science content (Ritchie, Tobin, Hudson, Roth, & Mergard, 2011). What began as a positive, emotional experience and a connection between myself and my teacher, translated into negative emotional energy as I moved to middle school.

Middle school is mostly a blur but the emotion I attach to this time is disappointment. What happened to that discipline that I once found so exciting? The amalgamation of facts, with no relation to my middle school life cut me off from

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[1] *Mr. Wizard's World* was an American television program for children, which first aired as *Watch Mr. Wizard* in 1951 and was revived in the 1980s. It was a general science experiments show that explained the science behind ordinary things and aimed to make science both understandable and exciting for children.

science. Instead, I wrote notes to my friends and even fell asleep in class. I was still an excellent science student, but my interest had certainly dwindled. Research suggests that my experience is common. Girls perform as well as boys in middle school science courses, even though many of these same girls do not study science in college or pursue a STEM career (Hill, Corbett, & St. Rose, 2010). Middle school often results in a significant drop in attitude, interest, and efficacy in science (Sorge, 2007). In addition, gender differences in science efficacy and interest emerge as early as middle school (Hill, Corbett, & St. Rose, 2010). Interestingly, African-American girls show more interest in science than white counterparts (Hanson, 2004). Research suggests that these racial differences in attitudes and interest also begin to surface in middle school. In middle school, my experience lined up with the data. As a white middle school girl, I was not interested in science or a STEM career trajectory. I, like many girls my age, conceptualized STEM careers as white male- dominated, nerdy, boring, isolating, and overly competitive (Hill, Corbett, & St. Rose, 2010; Bolstad & Hipkins, 2008).

In high school, I was introduced to the power of choice and tracking of students. Here, I could finally have a say in what courses to take but I also began a program of study, which left other students behind and totally separate from my educational experience. This represented the school experience of many high school students in a tracked environment. Tracking is the practice of grouping students into separate classes or courses based on their prior academic achievement. Research suggests that enrollment in an academic track is a fundamental predictor of learning opportunities in public secondary education (Kilgore, 1991). I was fortunate to be enrolled in the academic track, which allowed me to pursue academic choices in line with college aspirations. I decided that I loved biology after freshmen year, but I felt that science stifled my creativity. This led me to delve into the creative arts; I took photography and creative writing as electives. It was in creative writing that Mr. Markarian went beyond merely teaching, to inspiring his students. He had this way of making you feel like you truly could accomplish anything you set out to do, while at the same time pushing you to always strive to do better and live up to, or even surpass, your potential. Mr. Markarian, whom I respected so much, was convinced that someday I would become a teacher. Like Mr. Nagel, Mr. Markarian represented the importance of teachers and the influence that they can have. The research has clearly shown that quality teaching matters to student learning and in fact is the most important school-based factor in student achievement (e.g., McCaffrey, Lockwood, Koretz, & Hamilton, 2003; Wright, Horn, & Sanders 1997). Out of respect for him I began to quietly consider becoming a teacher. I was not yet persuaded and did not yet see how teaching science could bring together my love of biology and my thirst for involvement in a creative enterprise.

Science as embedded in life. I never really loved school science as much as I did in fifth grade. Although I enjoyed my biology class, I didn't believe that science was really for me. I was good at science; I excelled in science; I had potential in science. But, I did not love science at school. I never really had a passion for it. This developed later and was nurtured by my life experiences, most notably, my experience with a hereditary disease. At the age of 10, my cousin was diagnosed with muscular dystrophy. Although I knew about his diagnosis when I was in middle school, I did not see the consequences of the disease until the summer before I entered college. During that summer, I volunteered as a counselor at the annual Muscular Dystrophy Association[2] summer camp. What I saw here truly altered the course of my life. I entered the camp a selfish 17-year-old girl, who cried when she was denied a red sports car for the more practical, economical Ford Escort. Yet, I left with an impassioned desire to do whatever I could to give back to others since I knew I had the ability to make such a difference. My emotional connection was grounded in this experience and resulted in persisting confidence, enthusiasm, and desire for action (Collins, 2004) related to advancing the moral and societal aspects of learning science.

Alternative Routes to Teaching

Attending college was always in my plans. Although my father had never graduated from high school and my mother dropped out of college, my step-dad had completed law school and the expectation was that I would go to college, too. Additionally, I was continually told that my skills in writing and the sciences could lead me to follow in my grandfather's footsteps. I had never met my grandfather because he passed away when my mother was 12, but I was told he was a skilled scientist and remarkable engineer. When I finally received college acceptance letters,

[2] For more information about the Muscular Dystrophy Association visit www.mdausa.org

I couldn't believe that I had gotten into Cornell University and Brown University;[3] my teachers told me that only relatives of the Kennedys[4] could accomplish this feat. In fact, the guidance counselors were pushing me towards community college, my parents were pushing me towards state schools, and I was fighting to go to Cornell or Brown. As a student, I had worked extremely hard to be at the top of my class and wanted a college education that reflected that effort. I firmly believed that because these schools were rated in the top 15 of all universities in the U.S., that I would get a higher quality education there. We finally met in the middle and I attended the state-subsidized school of Cornell University. This financially driven decision began the journey that would eventually culminate in my role as a science teacher in an urban school district.

My experiences with school science and experience with MDA influenced my decision to enter Cornell to become a doctor with a major in development sociology in order to gain the broader perspective I felt would be necessary to be a successful physician. By focusing on sociology I believed I could better connect to the cultural, institutional, and historical context necessary to serve an individual patient. However, as college progressed, I realized that I did not want to be a doctor, despite my ability in science and the pressure from my family and friends to do so. Eventually, I recognized that just because I could become a doctor, didn't mean that I must become one. But now, what was I going to do? I didn't want to waste all of those hours I had put into my science classes! I decided I would double major: biology with a concentration in nutritional sciences and development sociology. How could I combine my newfound passion for science with my commitment to helping others and my inherent interest in sociology? That decision was cemented in my final semester of college when I met Chavez in a course called *The Art of Teaching.*

College and the art of teaching. In my senior year of college, I took a course called *The Art of Teaching*. This course was designed for students of all backgrounds and interests that had a desire to learn more about education and teaching. This was

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[3] Cornell University and Brown University are competitive, private schools in the United States that are a part of the Ivy League. The Ivy League includes 8 universities that have had common interests in scholarship as well as athletics. In 2000, the acceptance rate for applicants was 30.5% and 15%, respectively.

[4] The Kennedy family is prominent in United States politics and government. They are wealthy and educated in the top-rated Ivy League schools. This comment suggests that only those with wealth and power can achieve admission to these selective schools.

the only education course that I took in my four years of college, but it had a lasting impact on my life, specifically because of the fieldwork component of the course. Over the course of the semester I completed my fieldwork at what I refer to here as the Juvenile Center. This facility was for male juvenile offenders aged 13-18. At the Juvenile Center, most of the residents were placed at the facility away from their homes in urban areas of NY State. The facility offered academic programs, vocational training, and group counseling to the residents. As part of my fieldwork experience, I would visit the Juvenile Center for two hours per week and tutor students to prepare them to pass the test to earn their General Education Diploma (GED). What I learned about education there stays with me today.

At the beginning of the field experience I set goals around what I would accomplish and analyzed concerns that I had about my field experience. Prior to my first visit, I feared being unable to motivate my students and I was concerned about my familiarity with the GED[5] and my preparedness to tutor students successfully. Even as a novice teacher, I recognized the fundamental issues of content knowledge and pedagogy so significant to teaching. As a part of the course, I wrote an essay addressing my goals and concerns. I wrote:

> The GED is a complicated, specific test that requires preparedness and understanding before strategy and material can be taught. With no prior exposure to this exam it is difficult to confidently instruct a student on its material and format. In order to effectively teach it is important to be familiar with the material and prepared to answer questions with assurance…With respect to the learners I fear being unable to motivate those I tutor, especially regarding the desire to learn. The students at the Juvenile Center may feel as though they are unable to learn the material and thus decide not to put in any effort. Building on this concern is the worry that the students at the Gossett Center have a poor outlook of their future. In other words, the students feel as though they have no options because even with a diploma they are still caught up in their social circumstances upon release. (The Art of Teaching, Goals & Concerns Essay, 2003)

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[5] The General Educational Development, or GED, test is a group of five subject tests which, when passed, certify that the taker has American or Canadian high school-level academic skills.

I addressed my concerns early on by proactively cultivating a plan to address my anticipated situation. Because the field experiences for each student differed, our instructor gave each of us the freedom to plan and implement a unique approach at our site. I decided I would purchase GED study guides, research more about the test online and speak with people who had received their GED. In addition, to motivate students, I was determined to approach each student with the mindset that they will inevitably succeed and approach them with the conviction that they will learn. My initial sense was that by encouraging my students and commending them for each small win, I could motivate students to put in the effort necessary to learn and excel.

When I arrived at the Juvenile Center, the physical environment and interactions among students and staff were the most surprising. In a reflection log, after one of my tutoring sessions, I recorded the following incident:

> The staff member supervising our tutoring situation said, “He isn’t even trying is he?” Carrie and I continued to tutor our students without supplying an answer to his question. As we continued to work through the math lessons and focus on specific problems the supervisor continued to oversee the lesson. At one point the supervisor handed Carrie and I a small pouch containing Tylenol. At first, neither of us responded. As the supervisor pointed out the small gift before us we were forced to acknowledge our receipt. At this point he said, about the Tylenol, “You’re going to need this when you are done helping these kids.” (The Art of Teaching, reflection log, 2003)

I was frustrated that this staff member interacted with us in this way, while we were working with the students. I was also frustrated that I didn’t know how to respond. It was clear that the students were discouraged but not surprised by his admonishment, making it seem that this was commonplace. In contrast, our interactions were always respectful and I valued the time that I spent with the students. Our interactions served to build solidarity and achieve positive emotional energy. Over the course of my time at the Juvenile Center, I came to see the importance of the relationship that we had built and saw this as an essential principle of teaching that I had missed in the beginning. While initially my concerns dealt primarily with the categories of teacher, learners and subject matter, the interactions among and the development of a trusting relationship came to the forefront. I realized that relationship building was not subsidiary to teaching, but rather, teaching cannot take place without a productive relationship with students. These positive interaction rituals helped to create positive emotional energy that built rapport and afforded us the opportunity to concentrate on learning content needed for the GED. In one particular interaction with a student named Chavez I came to understand education as so much more than a body of knowledge. In my final reflection I wrote:

> Chavez wants to know information for its general good. He tells me that he believes that he should understand science and the other components of the GED in order to "be in the world." Whether he takes the test or not, goes to college or not, even becomes a world famous basketball star, he has a genuine interest in learning the material. (The Art of Teaching, Reflection log, 2003)

At the time, this surprised me. Why should a student, convicted of attempted murder, serving time in juvenile detention center far from home, with dreams of being a rapper or an NBA star, want to learn the material or even take the GED? Why would Chavez, who had difficulty reading at a fifth grade reading level and stumbled over words, be motivated during these tutoring sessions? It was not until we talked about teaching and learning and his cultural, historical background that I understood the true power of teaching. Through this experience, I came to realize that education was about liberation. He recognized and taught me this. And in that vein, I wanted nothing more than to liberate other students and follow the path to becoming a teacher. This experience ultimately resulted in my application to a program called Teach for America (TFA). TFA is a national teacher corps of recent college graduates and professionals of all backgrounds who commit two years to teach and to effect change in under-resourced urban and rural public schools. The mission of TFA—to build the movement to eliminate educational inequity by developing leaders—was in line with my passion for helping other students like Chavez.

On doing Teach for America in Camden. "You went to Cornell to become just a teacher?" This was the response I got from my stepfather when I first unveiled my decision to embark on a teaching career in Camden, NJ. I found out I was accepted to TFA to teach high school science, shortly before the beginning of my last semester of college. I was excited and unsure of what the future would bring. When you apply to TFA you preference the content, grade level, and in which city that you would like to teach. As part of my acceptance to TFA, I received an initial teaching assignment and placement city—high school science in Camden, NJ. I didn't know what science discipline I would teach or anything about Camden, NJ, but I knew that I desperately wanted to teach and believed in the mission of the organization. Teaching in Camden, NJ as part of TFA would be the beginning of my career focused on science education.

This journey to a career in education may not be typical or traditional. However, no longer do teachers only come to teaching through traditional, undergraduate education programs. In the United States, approximately one-third of new teachers being hired have been prepared through alternative routes to teacher certification (National Center for Alternative Certification, 2010). These numbers have been steadily rising, with over 500,000 teachers having entered the teaching profession through alternative routes to teacher education programs since the mid-1980s (NCAC, 2010). My story is representative of the increasing number of those who teach—we come to teaching through alternative routes, many of us in order to strive for educational equity. Our trajectory to education comes from the recognition that our work in education is a life-long campaign for civil rights and social justice. Chavez had taught me about the importance of a quality education for citizenship and I wanted to be a part of the movement for educational equity for students like him.

That first summer, I participated in pre-corps training, which included a five-week institute where I taught summer school biology in the Bronx, NY and took a crash course on classroom management, lesson planning and teaching practices. Although I was slated to teach in Camden, NJ, the Bronx, NY served as a centralized hub for many Teach for America teachers who would teach in urban centers on the eastern coast of the United States. The Bronx, NY is the northernmost of the five boroughs of New York City and is the third most densely populated county in the U.S. According to the 2010 Census, 53.5% of the Bronx's population was of Hispanic, Latino, or Spanish origin and 30.1% non-Hispanic Black or African American. TFA had a summer institute here because the demographics were similar to the cities where TFA teachers would start their teaching careers. The idea was to provide TFA corps members with a foundation of knowledge, skills, and mindsets needed to be effective beginning teachers while making an immediate impact on the students in summer school. Teaching biology in the Bronx was challenging, because I had little understanding of the students and they came to school with their own set of personal difficulties and were far below grade level. In addition, we had little understanding of how best to teach science to students and although the pre-corps training included coursework, these sessions were not content specific and proved difficult to implement effectively.

During the summer institute, I collaborated with other new teachers, made parent phone calls and for the first time struggled to put into practice all that I was learning through my coursework. I worked to plan and execute engaging lessons, give and use effective assessments, and create and implement a classroom management plan. For the first time I recognized the hard work of teaching that had always been invisible to me as a student. I came to realize that for the unforeseeable future of my teaching career, my life would be filled with all-night lesson planning, piles of papers, tears, science songs, phone calls home, professional development and the daily grind that makes it possible for our students to “be in the world.” What I did not yet know was the profound journey I would embark on or the impact that this lifestyle would have on my career path.

Role of Science and Pedagogy in Science Teaching

During summer institute in the Bronx, NY, I began to feel that teaching science was somehow different than teaching math or teaching English. My experiences during my first year of teaching contributed to this idea. I started to see the interactions between science content, pedagogy, and the culture of my students. In this section, I explore my experience as a first year teacher and the limitations of my training for meeting the challenges I faced as a new teacher. I continue to apply the lens of emotional energy, while also introducing structure and agency to analyze these experiences.

Teaching Science at the High School for the Arts (HSA)

> Camden was originally an accident, but I shall never be sorry I was left over in Camden. It has brought me blessed returns. – Walt Whitman (Moss, 1998)

For me, Camden was similarly a sort of “accident” because it was the placement I received from TFA, and I do not regret beginning my teaching career there; Camden was truly a blessing that has impacted the course of my life. When I arrived in Camden for the very first time, I was shocked by what I saw. During the initial city tour, I was dismayed by the city landscape, which was dominated by boarded up houses, graffiti covered buildings, and run down corner stores. This tour, through 9-square miles, revealed crumbling infrastructure, abandoned homes, and memorials to mark lives lost to violence. It surprises me to recall this initial shock, because over time I became desensitized and accustomed to what I saw. Growing up in a small city near Buffalo, NY, I had never spent time in areas of a city truly ravaged by the effects of poverty. Although some parts of Buffalo, NY were similar, I had spent very little time in these areas and had little exposure. I grew up on a quiet street of North Tonawanda, NY, a city with demographics that are very different from those of Camden, NJ. As of the 2010 Census, the population of North Tonawanda was 96.5% White with a median household income of $46,538. In contrast, according to the 2010 Census, the racial makeup of Camden was 17.6% White and 48.1% Black or African American. The Hispanic population of any race was 47.0% of the population. Camden, NJ is a city with high rates of crime and poverty, with the average household income hovering just around $26,000 a year (Guy, 2013). I was truly a stranger in Camden, NJ, and it would take me time to develop the cultural capital necessary for connecting to students and their families in ways that fully supported their science identities

I began my first year of teaching at a school which I refer to in this chapter as the High School for the Arts (HAS), a small, public, magnet school that was designed for students interested in pursuing careers in the creative and performing arts. Similar to the city, the school building was rundown and in need of repair (see Figure 2). It was an old elementary school converted to a high school building when school buildings were no longer needed, due to the decreasing population of the city of Camden.

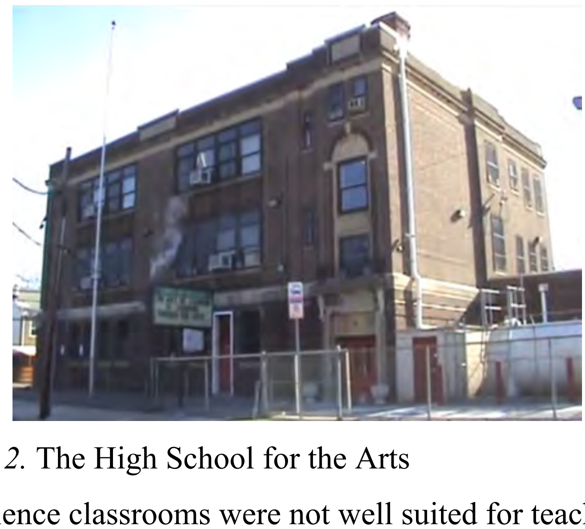

Figure 2. The High School for the Arts

The science classrooms were not well suited for teaching science. Although the classroom had lab tables, there were no working outlets for microscopes, no gas for Bunsen burners, and no sinks for simple wet labs. The picture on the following page

(Figure 3) shows the science classroom I shared with two other teachers and used for teaching both chemistry and biology lessons.

Figure 3. Science classroom at the High School for the Arts.

The school was so different from the school I had attended (see Figure 4), which was updated and had science laboratories specifically outfitted for each of the school science subjects. In the early 1990s, North Tonawanda High School used $3.1 million to add a state-of-the-art science wing addition in order to “ensure that specialized classrooms and facilities were well-equipped and maintained to enable a safe and effective learning environment” (TRM Architect, 1992). As I was introduced to my classroom, I recognized that this was a classroom environment that would require me to significantly alter my classroom teaching in order to make sure the laboratories were done in a way that was safe and effective. This was my first experience with specific structures—science equipment and classroom resources—that would hinder my ability to implement the type of teaching that aligned with my vision for an excellent science education.

Figure 4. North Tonawanda High School (left) and science wing (right).

In mid-August I was finally given my specific teaching assignment and I was to start teaching two weeks later! I was told I would be teaching physics and chemistry—neither of which I was certified to teach because I had both majored in and taken tests which certified me to teach biology. I was nervous for the challenge and spoke with an assistant principal about my reservations. I felt that solid knowledge of science content would be essential as I figured out how to teach this to others. Research supports this notion suggesting that teachers' knowledge of science content significantly influences classroom practice (e.g., Sanders, Borko, & Lockard, 1993). Additionally, I learned there was no formal curriculum or scope and sequence and I was handed a chemistry and physics textbook from which I was supposed to teach. I felt disempowered because I felt that I did not have the resources—schematic or material—to effectively prepare to teach. I was not sure how to transpose the knowledge and beliefs I had about teaching biology to this new situation. However, I took the textbooks home and began to plan my lessons, using what I knew about lesson planning from my pre-corps TFA training.

A few days later, I received a phone call saying that one of the veteran teachers was willing to teach the physics class and so I was re-assigned to teach all sections of 10th grade biology in addition to 11th grade chemistry. The time I had spent planning to teach physics had been wasted, but at least I would be teaching one of the sciences in which I was certified. I received my teaching schedule, which assigned me to teach 2 sections of biology and 3 sections of chemistry. The students I had were "forced" to take four years of science and were much more interested in their majors—dance, drama, creative writing, instrumental music, vocal music or visual arts—than they were in learning science. My students did not look like me and their life experiences had been very different from my own. In my school, 75% of students were black, 25% were Latino. The school was considered high poverty based on the fact that 68% of students were qualified for and received federal free and reduced lunch (Merrill, 2006).

During my first year of teaching, I struggled. The central philosophy of the TFA approach is the Teaching as Leadership framework. This framework includes the principles that TFA believes successful teachers take to lead their students to success, including instructional planning and delivery; investment, classroom management, and culture; diversity, community, and achievement; and literacy development (Teach for America, 2014). Although I was equipped with the 5-step lesson plan[6] as my canon and had been trained in diversity, community and achievement (DCA) through TFA, I was still met with many failures. TFA had very structured courses and set of espoused beliefs that suggested that as long as teachers planned meticulously, using the template they provided, and committed to their students, they would excel in the classroom. My access to schemas and resources from TFA limited my agency in my new situation. There was no room in the TFA training model for understanding pedagogy—or the theoretical conceptions of teaching and learning—and DCA training was focused on building relationships with students and their families independent of the content. The 5-step lesson plan, which included (1) Lesson Opening; (2) Intro to New Material; (3) Guided Practice; (4) Independent Practice; and (5) Closing, was given to teachers of all grade levels and subject-areas as the only way to structure a lesson and there was no room to consider the identity of the learner as you planned your lesson.

In spite of the crash course from TFA, I experienced many failures as a science teacher. I failed to engage students in science, failed to build relationships, failed to connect with parents and families, and I failed to ensure no students would fall through the cracks. Consistent with literature, I experienced constraints to implementing inquiry-based science teaching because I lacked an understanding of scientific inquiry, had little pedagogical content knowledge, and had concerns about management and student discipline (Roehrig & Luft, 2004). This led me to create science lessons based on my traditional experience as a learner of science and my limited knowledge of teaching from coursework through TFA and alternative route certification classes. During these initial months, I didn't use a theoretical lens to examine my teaching practice. When I failed, I worked harder and planned more. I spent more time at school scripting out what I would say the next day. I planned what I saw as more engaging lessons. I called parents. I offered extra credit assignments. I worked with the teachers of the arts to hold students accountable to do their work. When things didn't work I became frustrated and so did my students. I felt limited in my capacity for agency, enjoyed teaching less and was unsure where to turn for a new approach.

At the end of the year, what I discovered through student reflections surprised and disappointed me. Although I had worked extremely hard planning and executing

[6] Teach for America introduced and required corps members to use the 5-step lesson plan, which was adapted from Madeline Hunter's direct instruction lesson plan.

my lessons, some of my students were concerned more about my attitude in the classroom, than my lesson design. For example, students wrote that they thought I gave off a negative attitude towards them or confided that they didn't feel that I adequately recognized their accomplishments. They pointed out that I was quick to provide feedback on how to improve, but was not good at positively praising their successes. As I looked back on my year, I realized that my frustrations in the classroom had become palpable to my students and that I had been so focused on the shortcomings—of myself as a teacher—and my students as scientists—that I forgot to celebrate our successes. While I was trying to exhibit high expectations and create a safe and orderly environment in which to push my students toward academic excellence, the way that I was approaching them created cultural conflict within the classroom. Therefore, instead of promoting positive emotional energy, these negative interactions led to negative emotional energy that was prohibitive to the teaching and learning of science. The students articulated this tension that I had felt at various times throughout the year. Students had noticed that I began the year positive and optimistic and ended the year frustrated and unhappy with the classroom flow and academic progress.

The second year of teaching was better than the first. I had more confidence and had built relationships with many of my students. However, the summer after that second year I began a master's program for in-service science teachers that enabled me to effectively describe my experiences as a first year teacher and improve my practice. In the section that follows I explain the program and the ways in which it shaped my beliefs, attitudes and habits and allowed me to view my experiences differently. In this section I bring in the framework of transformational teacher leadership to analyze my development in the program.

Professional Development for Science Education Reform

Professional development is an integral component of the life of a teacher. Many states have specific requirements for teachers to encourage them to continue learning on the job and schools and districts often provide days for professional development. During my first two years of teaching, much of the professional development I received was not specific to urban teaching, to teaching science, or to the specific challenges I was facing. PD through my alternate route program and in my school was focused on general teaching strategies and was often repetitive. We learned about Bloom's taxonomy for developing objectives and other foundational teaching methods and strategies.

NSTP as a Springboard for Pedagogical Content Knowledge

After my second year of teaching, I stumbled upon the Northeast Science Teacher Program (NSTP), which would turn out to be a unique professional development experience that propelled my career in a different direction. After completing my alternate route coursework, I was still seeking more knowledge and guidance, specifically about teaching science. In addition, the requirements for a highly qualified teacher in New Jersey required that I receive more credits in chemistry in order to continue to teach this subject. Together, these factors motivated me to look for a program that would meet my needs. Looking at programs that were offered at nearby universities, I came across the website for NSTP. Based on the chemistry-focused curriculum, I could enroll in this program and acquire the additional science credits while simultaneously learning more about the teaching and learning of science, specifically.

When I enrolled in NSTP, I was excited to network with other science teachers and to earn a master's degree from a prestigious university. I did not anticipate the lessons that I would learn or that this experience would truly transform my classroom and my career path. During the application process, I was asked to engage in a number of activities I had never done before which set the stage for a novel approach to teaching and learning science. First, I wrote a philosophy of education and a statement about teacher leadership. Although as part of TFA I took courses as part of the framework called *Teaching as Leadership*, I had never considered what it meant to be a teacher leader, nor had I examined my teaching practice for indicators. This was the beginning of my exploration of pedagogy and science teacher leadership.

The NSTP program was developed to increase the content knowledge of science teachers, and change the teaching and learning methodologies used in science classrooms to research-based promising pedagogical practices. To do this, the program structure included 10 courses, eight of which were chemistry content and two, which were chemistry education, all designed specifically for secondary science teachers. The NSTP program was designed for cohorts to complete over 26 months—three consecutive summers and two intervening academic years. To demonstrate growth, degree requirements included an electronic portfolio, a comprehensive content examination after the completion of the teen courses, and a written research paper.

Through my coursework at the NSTP, I realized that inquiring into your own practice is the most powerful learning experience you can engage in as a teacher and that it was important to consider the way that content and pedagogy intersect in order to develop reformed science teaching praxis and transformational leadership within and beyond the classroom. The NSTP focused on pedagogy, science education, and classroom research and exposed me to the theoretical frameworks needed to be reflexive about the successes and failures of my teaching. Through the NSTP I developed the capacity for transformational science teacher leadership, focused on facilitating a vision for science education through collaborative professional learning. Having the language and theory in which to view my experiences enabled me to purposefully reflect on my practice in order to transform the way in which I conceptualized teaching and learning of science and interacted with my students to facilitate their academic success.

One way that I did this was to use my new pedagogical knowledge to design instruction. As part of the NSTP, I submitted a baseline unit plan. My analysis of my baseline unit plan revealed that my lessons were constructed through planning day to day, rather than planning with the end in mind. When I evaluated my lesson plan, I highlighted areas for improvement, including pre-assessment, meaningful application student reflection, student attitudes about science and nature of science. Figure 5 shows my self-evaluation where I rated myself as “needs improvement” in these areas.

Academic Year 2006-2007
Unit Plan feedback

Criteria	Exemplary	Making Progress	Needs Improvement
Pre-Assessment (WEIGHT 2)	The lesson plan is structured to actively solicit students' preconceptions at the start of a topic, and refers to possible ways in which instruction could be modified in response to pre-assessment information.	The lesson plan does include pre-assessment activities, but information is not used to inform instruction OR teacher simply attempts to refute or replace misconceptions with correct information. X during teaching	The lesson does not reflect an understanding that students' preconceptions can affect how they understand new information. X
Meaningful Application (WEIGHT 2)	○ Content is given a meaningful personal context for students ○ Content is portrayed as significant to real world issues	Some attempt is made to give content a meaningful personal context or real-world significance X Certain "hooks" and demos	Content is largely devoid of real world relevance or student-engaging context. X
Student Reflection (WEIGHT 2)	Either individually or as a class, students are required to reflect on and summarize their understanding verbally or in writing at an appropriate point(s) during the unit in order to build conceptual understanding.	Lesson is structured to allow for (but not fully promote or support) meaningful student reflection or summation that furthers conceptual understanding.	Time is not reserved for student summation or other reflective practices. X
Assessment (WEIGHT 3)	○ Includes effective tool(s) that assess for conceptual understanding (PROJECT) – BALANCING ○ Includes criteria and/or rubrics for performance-based assessments ○ Assessment results used as formative feedback to students & teacher	Includes tools or suggestions for assessment that may address conceptual understanding but emphasize factual recall	Assessment tools do not measure student conceptual understanding OR there is no assessment tool or method described

LESSON DESIGN AND IMPLEMENTATION – SOCIOCULTURAL AND AFFECTIVE ISSUES

Criteria	Exemplary	Making Progress	Needs Improvement
Student attitudes about science (WEIGHT 1)	The teacher's lesson objectives or activities are designed to affect a change in student values, attitudes or beliefs about the importance and appeal of science, their ability or desire to learn science, etc. Students attitudes and beliefs are evaluated in order to measure progress toward these goals.	The lesson objectives and/or activities imply a desire for changing student values, attitudes or beliefs about science, but no means for measuring such change is utilized.	Lesson objectives and activities are exclusively cognitive and include no implied desire for changing student values, attitudes or beliefs about science. X

Figure 5. Self-evaluation of baseline unit plan.

As I was exposed to pedagogical knowledge, I was able to identify the issues in my lesson design and consider alternate approaches that would more accurately reflect reform-based science teaching and take into account my students' identities. At the end of the program I created a new unit plan based on what I had learned. My reflection on this growth is below:

> This shows my growth because in the beginning I self-evaluated my baseline rubric and found that I did not explicitly address students' preconceptions (pre-assessment) nor did I integrate real world relevance to really engage my students (meaningful application). In my new unit plan, I not only thought about possible areas of misconception, but I also integrated anticipation guides as a way to gage knowledge of content. Additionally, since the entire unit relates to the potential for pesticides to act as environmental pollutants and culminates in an authentic proposal to the Stockholm Convention, there is a built in relevance of chemistry content. Two other areas of growth include student reflection and student attitudes about science. Initially I rated myself as "needs improvement" in this criteria. However, in my thesis unit plan I integrated a journal and reflection questions to allow students to reflect on and summarize their understanding in writing throughout the unit.

> Additionally, I really tried to design activities that would affect a change in student values, attitudes and beliefs about science. In fact, pesticides are all around us and by using this as a theme for learning science I was able to create a unit plan that can help students make informed decisions in their everyday lives and gain an appreciation for science. Finally, I was able to not merely present science as a body of facts (nature of science) but truly focus on how theories are tentative and science is a social endeavor involving argumentation. Notably, my thesis unit plan directly involves students in the process of argumentation and highlights the disagreement of scientists and change in apparent properties of pesticides over time. (e-portfolio excerpt, 2008)

Based on my the knowledge of content, pedagogy and education literature, I was able to more effectively create lessons that were based on pedagogy as well as content and create a classroom culture where I recognized what my students brought to the classroom and cultivated shared responsibility. As part of my praxis, I continued to find creative ways for students to coparticipate in learning science. To do this, I created more opportunities for students to build on their own cultural experiences to learn science. Students were given the chance to complete alternative and authentic assessments to demonstrate their own learning. Since many of them were interested in the creative and performing arts, poetry and song became a key strategy for communicating their understanding. Although I continued to hold high expectations for academic achievement, as demonstrated by being able to respond to questions written for standardized assessments, the classroom became a place where students could bring their unique talents and cultural character to learn science and share their distinctive contributions within a collaborative classroom environment. For example, students were able to write songs, perform their understanding of specific concepts, and take written assessments. Figure 6 shows two students doing a performance to demonstrate their understanding of biology concepts.

Figure 6. Students perform a song to demonstrate their knowledge.

These successful interactions, as demonstrated by the facial expressions and mutual focus of the students (Figure 6), created positive emotional energy that provided the foundation for learning science.

The NSTP gave me the resources I needed to transform my practice. I was able to access these resources and appropriate them in my own classroom in a way that made me an agent for pedagogical change. The way that I approached science teaching and learning was informed by the new schema and resources I had at my disposal. As a member of a cohort of teacher leaders in the NSTP, I learned to approach the teaching and learning of chemistry with a new lens. My capacity for leadership practice was improved as I was empowered to act with and against others by the schema and resources that I could apply in my school context. In the section that follows, I discuss how the NSTP led me to see the importance of leadership in science education reform.

Science Leadership for Reform

Leadership is essential for creating the vision for a school and inducing all stakeholders to work together in order to promote changes in instruction and improve student learning (Bryk et al. 2010, Neumerski, 2013; Spillane & Diamond, 2007). The extent to which teachers are supported to implement reform science teaching practices is dependent upon the administrative practices of district and building-level decision-makers, including superintendents, principals and vice-principals, science supervisors/curriculum leaders, and science department chairs. In order for NSTP to effect change, the program directors realized that they needed to consider how to form a community of teachers and administrators dedicated to the teaching and learning of science to their students. Research suggests that the degree of subject specialization, especially at the secondary level, can serve to exclude a specialist in another subject area from supporting effective pedagogy (MacNeill et al., 2005). Furthermore, in order to be effective pedagogic leaders, administrators must have sufficient leadership content knowledge (LCK) to support teachers.

One component of the NSTP approach was to provide financial support to teachers if districts agreed to be a Core Partner of the program. To become a Core Partner, a district would agree to have an administrator participate in a professional development academy focused on science content and pedagogy and the coursework of the science teachers in the program, as a means for building pedagogic leadership and leadership content knowledge. In return for partnering with the program, all teachers from the district who were accepted to the program earned the degree for free, with a stipend. It was through this process that I began to engage the administration in my district and piqued my interest in the ways in which administrators support the teaching and learning of science in schools. I worked with the district science coordinator who agreed to participate in the six day long Administrators' Science Institute (ASI) sessions and the superintendent signed off that she would provide support in the form of a commitment to the reform of science education in our district. The activities that served to induct me into the NSTP became the foundation on which my teaching practice stood and still are essential to my research and practice today.

The ASI was designed in collaboration with a center for educational leadership situated at the university in order to result in a Leadership Certificate in Science Education for each participating administrator. In order to maintain a science focus, the ASI was fully planned by the program director and consultant Dr. Sonya Martin, a science educator at Drexel University, and the PCEL was "utilized where their expertise intersects with the PSTI goal, namely, working with administrators on leadership issues" (Kahle, J. B., Li, Y., & Scantlebury, 2009). The ASI was initiated by NSTP program directors in order to foster administrators' understanding of the changes and innovations in science instruction, to investigate how to evaluate such instruction, to introduce administrators to hands-on science instruction, and to provide opportunities for discussion with administrative colleagues (Kahle, J. B., Li, Y., & Scantlebury, K., 2009). When I began the NSTP program, the ASI was already in place. NSTP, as a Math Science Partnership (MSP) program initiative of the

National Science Foundation (NSF), was focused on the development of science teachers as school and district-based intellectual leaders and master teachers. The program created a Core Partner Program to encourage participation of administrators of each teacher participant. This program was created in order to alleviate perceptions of teachers and address the research evidence that administrators stand in the way of teacher initiated changes in instruction and curriculum. The Core Partner Program created partnerships between disciplinary faculty in science content and education departments of higher education institutions with both administrators and teachers in K-12 districts and schools. In return for fully funding the master's program for the teacher participant, the Core Partner agreed to designate a district representative to help recruit more teacher participants from within the district, provide a letter from the superintendent showing a commitment to science education, identify a building administrator to actively participate in the ASI and allow data collection for research and program evaluation from students, teachers and administrators. This was proposed to help make the reform efforts supported by NSTP more easily integrated into schools and districts.

Challenges to Science Leadership Practice

When I applied to the NSTP, Camden City Public Schools were not yet Core Partners. This meant I had to find an administrator to join the program with me. I realized that I was completely isolated from central administration, and the superintendent was required to write and sign a letter supporting this effort. It was incredibly difficult to garner access to the superintendent and the instability of leadership made it almost impossible. For example, during the month that I called and visited the Board of Education, there was a change in superintendent meaning that I had to rely on the interim superintendent to sign off on the letter committing to (1) alignment of the NSTP teacher leadership effort with district educational reform in math and science; (2) increased responsibility for me as a teacher participant; (3) and administrative support, time resources and recognition due to this increased responsibility. Although these measures were put in place to break down barriers between administrators and teachers and provide pathways for teachers to gain support in implementing the inquiry-based teaching practices, in my case it was a formality. Despite signing this agreement, I never actually met or talked to the superintendent. This meant that even while I was learning about reform based teaching practices, the district and school-based leaders were not aware of this or how they could support me to bring this back to my classroom, the school, or the district. This point is salient because research supports that when administrators do not support reform measures, classroom teachers often find it difficult to sustain changes in their teaching practices (Jeanpierre, Oberhauser, & Freeman, 2005).

Interactions between Science Teacher Leader and Administrator

In order to participate in NSTP, I not only needed the superintendent's signature, but I also needed an administrator to participate. As a teacher applicant, I did not recognize the focus of the ASI on the building-level administrator and thought that the district level science supervisor, Mr. Mulligan, would be the most logical choice based on his interest in science and district-level impact. At the time, my principal seemed too busy to be burdened with what I saw as an additional commitment for her. When I approached Mr. Mulligan and asked him to do this, he was very excited by the opportunity. During the ASI Mr. Mulligan and the administrators from other districts focused on current science education research and best practices. Mr. Mulligan attended sessions focused on supervising and evaluating science teachers, especially in classrooms modeling inquiry-based teaching and learning and was introduced to the theory and practice of distributed leadership (Kahle, Li, & Scantlebury, 2009). Mr. Mulligan was very enthusiastic about his experience:

> I can summarize how my attendance at Academy sessions equips and supports me to support quality science instruction by reflecting on my first three responses here. Knowledge is a powerful tool needed for any endeavor. Academy sessions provide participants with the opportunity to learn from expert presenters in varied fields of science and education in general. We share with counterparts from other districts and interact with the teachers enrolled in the program as well as imparting the experience with district science teachers we work with. The Academy experience is a very positive one and I am most appreciative for the opportunity the University has made possible for me and our teaching staff. (Mulligan, email, 2009)

In fact, not only did he participate in the ASI the first year I was in the program, but he also attended the ASI a second time.

In addition to working with administrators to become pedagogic leaders by gaining knowledge, experience and practice that allowed them to communicate more meaningfully and with greater authority on the topic of inquiry-based instruction, program sessions also encouraged administrators to find ways to use teacher-participants as leaders to catalyze change at the building and district-level (Kahle, Li, & Scantlebury, 2009). Upon completing the ASI, Mr. Mulligan invited me to present at a district professional development for secondary science teachers on the NSTP and inquiry-based learning. This was my second year of the program and I was excited that I would be able to share the inquiry-based teaching strategies we were learning about in the NSTP with other Camden science teachers. In addition, I would be able to tell teachers about the program and encourage them to enroll in the program as well. I facilitated a session on Process Oriented Guided Inquiry Learning (POGIL)[7] while Mr. Mulligan presented and modeled an inquiry activity that he had experienced in the ASI. After this session, two other teachers from Camden enrolled in the NSTP. As a result of his actions, Mr. Mulligan was building capacity for district-level by encouraging other teachers to learn the science content, pedagogy, and leadership fostered by the NSTP.

In addition to this opportunity to develop as a science teacher leader, in my fourth year of teaching and final year of the NSTP program I was asked by my principal to lead the science in the building as department chair. The principal recognized the work I was doing and Mr. Mulligan encouraged me to take this position. Despite this legitimate role, I did not have the impact on science in my school that I had hoped. Although my principal was incredibly supportive, in words, of the science I was doing in my classroom, other actions were not in line with this support. For example, we did not have a budget dedicated to science materials and it was difficult to get the supplies we needed. Furthermore, my influence as science department chair was limited because the other teachers were not equally invested in pedagogic change and structures did not exist at the school level to facilitate collaborative, professional learning. This outcome resulted from the lack of

[7] Process-Oriented Guided Inquiry Learning, or POGIL, is a student-centered strategy that uses guided inquiry based on the learning cycle of exploration, concept invention and application to guide students to construct new knowledge. More information can be found at https://pogil.org

leadership content knowledge of my principal, which precluded her from being a true pedagogic leader in support of science education reform.

I now recognize that the ASI was actually targeted to attract building level leaders based on two decades of research establishing that a focus on leadership is a key strategy for school improvement and that support for school-based leaders plays an important role in improving lower achieving schools (DeFlaminis, 2009). Having my building principal engaged in the ASI may have developed her as a pedagogic leader by giving her the credible knowledge of science teaching and learning (leadership content knowledge) necessary to truly enact pedagogic change. However, because I did not bring her into the ASI, the opportunity for me to be a science teacher leader and lead reform at the school-level was thwarted and I was discouraged. I started to look for other opportunities to broaden my impact and saw this as something I needed to do from outside the classroom. Specific structures in my classroom context hindered my agency as a science teacher leader and led me to pursue other opportunities. I discuss this phenomenon in Chapter 6.

The NSTP program's goal was to provide in-service teachers with content knowledge, science education theory and model instructional strategies in order to encourage teachers to implement reform-based teaching practices in their classrooms. Additionally, program administrators expected the graduates to become teacher leaders in their schools and/or districts. However, despite the knowledge, skill and understandings teachers left the program with, there were still barriers to implementing what they had learned in their classrooms, schools and districts. One of the recurring "excuses," "reasons," or "perceptions," of numerous teachers was that administrators stand in the way of teacher initiated changes in instruction and curriculum. Although the ASI was created as an attempt to address this, the ASI found it difficult to attract administrators, a problem common to math/science teacher enhancement projects (Kahle, Li, & Scantlebury, 2009). In the section that follows I discuss my science teacher leadership practice while teaching in Camden, consider different definitions of science teacher leadership, and consider how structures in schools contribute to obstacles to science teacher leadership and potential outcomes of this.

Science Teacher Leadership

When I applied to the NSTP, I was asked to define leadership and describe my leadership roles. I described teacher leadership based on the definition I had learned through TFA's *Teaching as Leadership* coursework and philosophy:

> Teaching as leadership extends beyond the influence of the teacher in the classroom. It includes the teacher's collaborative efforts with teachers in other classrooms, the school as a whole and the community at large. All teachers should act as leaders, leading by promoting partnerships among teachers where best practices are shared, common problems solved and school-wide changes implemented. If a teacher has a vision of how a partnership with another teacher, the administration or the parents could improve the learning of students, that teacher is accountable for developing that relationship accordingly (application essay excerpt, 2006).

The definition I provided reflects the idea that many stakeholders, colleagues, parents, and administrators, should be involved in order to support school wide change (Jeanpierre et al., 2005; Martin, 2006). My description also highlights the ability of the teacher leader to build trust and rapport with colleagues, promote growth, and be a good communicator, which are aspects of transformational leadership (Pounder, 2006). However, my definition is not specific to science teaching and learning and is not necessarily in line with the leadership activities I describe in the paragraph that follows:

> As a teacher leader, I have facilitated professional growth among colleagues. I advise new teachers as a Teach for America learning team leader. I have worked within my team at team meetings to extend collaborative efforts among colleagues (application essay excerpt, 2006).

These leadership roles were those that took place outside of the daily work of being a teacher and involved facilitating learning with other teachers. My leadership roles did not involve school change and did not directly address student learning. I had difficulty identifying many examples of my leadership activity, especially since I had only been teaching for two years when I applied to the program.

Research and policy have not come to consensus about what constitutes "teacher leadership;" teacher leaders might promote changes in instruction, take on administrative duties, or hold a formal leadership role (Neumerski, 2013). Teacher leaders can be consultants, curriculum managers, department chairs, mentor teachers, professional development coordinators, resource teachers, specialists, coaches, and demonstration teachers (Mangin & Stoelinga, 2008). Based on a review of two decades of teacher leadership scholarship, York-Barr & Duke (2004) describe the expectations of teacher leaders: they support experienced teachers include being able to assess and prioritize district and teacher needs, know how to create a positive school culture, establish positive relationships with administrations, understand action research and inquiry, expand colleagues' instructional methods, and offer effective workshops and presentations. Based on these expectations, throughout participation in the program, I continued to grow as a science teacher leader. I facilitated professional development of science colleagues, sat on school-based leadership committees, and completed action research projects in my own classroom. However, despite this growth I still felt that I did not have the opportunities to be truly catalytic in leading pedagogic change.

On early leavers and vertical advancers. Through my coursework at the NSTP and my desire to contribute to the field I decided to leave the classroom and K-12 schools and pursue a doctoral degree in science education. Based on the interactions with my school administration and the other science teachers in my building, I felt limited in my ability to transform practice at my school and wanted to pursue a way to do this beyond my individual classroom. I became an "early leaver." I left the classroom after just four years of teaching science and almost immediately after finishing the degree where I had learned so much about reform-based science teaching that I never got to truly implement. My decision to leave called into question the influences of the program on my journey. Although the program sought to build me up as a teacher leader who could reform my classroom and school from the inside, my newly acquired knowledge and skills and the desire to learn and do more for the field of science education, led me to leave the classroom. My experience was not entirely unique. In my involvement with the program I learned about other teacher participants that had left the K-12 classroom to pursue other career opportunities—in science, in higher education, or to pursue doctoral degrees like I had. In addition to those that left K-12 education, some of the participants developed the knowledge and leadership capacity necessary to pursue administrative opportunities, such as lead teacher in another school, coordinators of curriculum and instruction, assistant principals, or building principals. This was an unintended consequence of the program, but an important outcome nonetheless.

Why Administrator and Teacher Leadership Matter

Over the last five years I have had the good fortune of working across boundaries, with scientists at the university, K-12 teachers, teacher educators, and administrators. In my position as a science educator with the Institute for School Partnership (ISP) at Washington University in St. Louis, we focus on strategically advancing teaching and learning within the K-12 education community. The ISP works with neighboring school districts in underserved communities in order to expand learning opportunities and develop professional development models that improve teaching and learning in schools. The ISP evolved from a Science Outreach program dedicated to bringing the resources of the university into K-12 schools through hands-on, inquiry-based science. The philosophy of the ISP, similar to that of the NSTP, is that only through long-term, sustained, and consistent professional development can instructional improvement be realized. The ISP enters long-term agreements with schools and districts to engage math and science teachers and school administrators in professional development. This approach has yielded results, as evidenced by the increase of reform-based science teaching and learning in partner schools, improved test scores, and development of pathways for teacher leadership.

Through my work in this program, I have recognized the power of content-specific knowledge for teachers and administrators as a key lever for promoting student learning. Yet, it is a constant struggle for building-level administrators to be pedagogic leaders, with the adequate leadership content knowledge to have their pulse on instruction in every classroom in a way that truly recognizes the ways in which a subject is best taught and learned. Additionally, while teachers can develop this expertise, there continue to be too few avenues for them to remain classroom teachers and become legitimate leaders in ways that transform pedagogy throughout their building. The questions in this dissertation have evolved as I transitioned from classroom science teacher to my new role as teacher educator. As a classroom teacher, emotions played a prominent role on my ability to influence the individual students in my classroom. However, as I moved from classroom teacher to doctoral student to teacher educator I began to recognize the broader issue of science leadership by teachers and administrators as instrumental in promoting reform. To analyze these issues, the theory of structure and transformational leader became more central lenses for thinking about science teacher experiences. In the next section I conclude this chapter by briefly summarizing the content of the dissertation and describing how this autoethnography informs my perspective.

Conclusions

This autoethnography is an important contribution to my dissertation because it provides insight into who I am and how my experiences influence what I studied, how I studied it and my interpretations of the topic. The longer I am in the field of science education, the more I learn about the complexities of teaching and learning science and about myself. My life experiences sparked my interest in the ways in which teachers are supported to transform their science classrooms and serve as leaders in their schools and districts in order to create transformational educational opportunities for students. In writing my autobiography, it became clearer to me that although teachers often come to their classrooms with knowledge and tools to enact science education reforms, the relationship between the teacher and their administrators often influences their ability to act. Especially since so few administrators have deep science pedagogical content knowledge, the ways in which administrators and teacher leaders work together is a critical area for research. Outlining successful administrative supports for teachers could help to promote the pace of science education reform, retain high quality teachers and encourage teacher leadership. To effectively take science education reform policy from rhetoric to action, will require a focus on teachers as leaders and strategies for providing administrators with the leadership content knowledge necessary to support their teachers. The research questions in this dissertation emerged based on reflection on my life experiences and the goals of the NSTP program for promoting science education reform. The remaining chapters focus on science teacher leadership (Chapter 5), the challenges that science teachers (Chapter 6) and administrators face (Chapter 4) as they try to implement science education reform, and the ways in which the MSP program for administrators and teachers influenced science leadership for reform (Chapters 4 and 6).

CHAPTER 3 – METHODOLOGY

> Mixed methods research is "practical" in the sense that the researcher is free to use all methods possible to address a research problem. It is also "practical" because individuals tend to solve problems using both numbers and words, they combine inductive and deductive thinking, and they employ skills in observing people as well as recording behavior. It is natural, then, for individuals to employ mixed methods research as the preferred mode of understanding the world. (Creswell & Plano-Clark, 2010, p.10)

In the above citation, John Creswell and Vicki Plano-Clark describe mixed methods research as human nature's problem solving approach. The multiple ways of seeing, hearing and interpreting are visible in everyday life and thus an accessible approach to inquiry. Doing a study that addresses the life experiences of science teachers and administrators requires the collection, analysis and mixing of both quantitative and qualitative data in order to provide a more complete understanding of the research questions. In this chapter I provide an overview of the research design. I begin by discussing how the autoethnography informed my mode of inquiry. I then provide an overview of the overall plan for my research—what I did and why I decided to do it in this way. What follows is a discussion of the theoretical frameworks and how they were applied across data chapters 4, 5, and 6. I then introduce the context of the study, including the participants, and provide an overview of the data sources and analytical framework used for each chapter.

Introduction

This dissertation employed a multiphase mixed-methods design in order to explore the intersection between administrator and science teacher leadership and the perceived role of this leadership in science education reform. The study included both quantitative and qualitative data gathered concurrently and sequentially. In the first phase of the dissertation, quantitative survey data was collected and analyzed in order to provide a foundation for the qualitative analysis that follows. The subsequent phases of analysis relied on an interpretive research paradigm to provide a detailed account of the emergent themes from the initial analyses. I explored a set of documentary evidence and use multiple stages and levels of coding (Strauss &

Corbin, 1998) in order to uncover the specific issues raised through the deductive approach and highlight patterns and contradictions.

Methods

Role of the Autoethnography

Philosophical assumptions consist of a set of beliefs or assumptions that guide inquiries (Guba and Lincoln, 2005). The worldview provides a general philosophical orientation to research. As an active participant in the Math Science Partnership (MSP) programs, I bring an emic perspective to this research. In an effort to more critically examine my own ontological and epistemological assumptions, I employed autoethnography in Chapter 2. While ontology is the nature of being or viewing social reality, epistemology is about the creation and dissemination of knowledge in particular areas of inquiry (David & Sutton, 2004). Taken together, ontology and epistemology are about knowledge and knowing, focused on how the individual acquires knowledge and the status of the knowledge in relation to reality (Lerman, 2000). The autoethnography was used as a method for producing meaningful and accessible research grounded in my own personal experiences (Ellis & Bochner, 2000) in order to explain how my own perspective, formed as a result of my own experiences, influenced my interpretation of data from participants in this study. The autoethnography served as a process of studying my own epistemological and ontological perspectives in order to underscore my worldview and personal constructions of phenomena that provided a foundation for this research and shaped how this research was conducted. Using autoethnography allowed me to have a deeper awareness of the ontological substructures informing my study so that I was better positioned to engage with this research project.

As an epistemological consideration, I adopted a practical stance in the design of the research, such that I collect and analyze data based on what works to answer the research questions. Epistemology refers to knowledge and knowledge acquisition and the nature of the relationship between the knower and what could be known (Guba & Lincoln, 1994). This dissertation was conducted by collecting, selecting and analyzing data informed by my own worldview and personal constructions of phenomena. The findings in this study are based both on my independent analysis, but are also influenced by the interactions that I had as a participant in the MSP programs. This point is salient, because I use the autoethnography to recognize my axiological assumptions, or the role of values, in my research (Creswell, 1994). In an axiological sense, I recognize that my research is biased and based on my interpretations and use the autoethography to explain how I came to focus on the four overarching topics of this dissertation: (1) coming to and leaving science teaching; (2) the role of science content and pedagogy in science teaching; (3) professional development for science education reform; and (4) science leadership (by administrators and teachers). In the section that follows I discuss the relevance of pragmatism as the paradigm for informing my mixed methods paradigm.

Mixed Methodologies

Consistent with mixed methods research, this dissertation considers multiple paradigms. This dialectical perspective "recognizes that different paradigms give rise to contradictory ideas and contested arguments—features of research that are to be honored but cannot be reconciled" (Creswell & Plano-Clark, 2010, p. 45). Therefore, approaching this study with a mixed methods design enables contradictions, tensions, and oppositions to emerge that are imminent when reflecting different ways of knowing about and valuing the social world. I chose a mixed methods design because the nature of my research questions required a more complex and nuanced effort than could be accomplished with a purely quantitative or purely qualitative approach. The mixed methods design allowed me to integrate more of the available data in order to tell a more complete story about the intersection between administrator and teacher leadership and science education reform. In this section I will describe how mixed methodology can bring together the advantages of quantitative and qualitative approaches in order to provide a deeper understanding of reality and develop robust conclusions in response to the research questions.

In mixed methods research, multiple worldviews can guide inquiry (Creswell & Plano-Clark, 2010). While using different paradigms can give rise to contradictory ideas, these tensions and oppositions also reflect and value different ways of knowing about the social world. While some contend that researchers can draw on more than one paradigm in their research (Creswell & Plano-Clark, 2010), this approach can be problematic because of contradictory ontological and epistemological assumptions from different paradigms (Feilzer, 2010). In order to address the ambiguity in the multiple paradigm approach, I use a pragmatist paradigm to guide my research because it served to encompass both qualitative and quantitative research methods and the inherent duality of the data analyzed (Feilzer, 2010). In this paradigm, the research design is based on the research questions and the researcher's desire to produce socially useful knowledge (Feilzer, 2010). The pragmatist paradigm is oriented toward mixing quantitative and qualitative methods in order to provide a more complete understanding of the research questions.

Quantitative research is typically embedded within a positivist paradigm (Cohen, Manion, and Morrison, 2011; Guba & Lincoln, 1994) and relies on numerical data to develop knowledge. In quantitative research, the researcher distances herself from the participants in order to objectively collect data and attempts to reject or fail to reject hypotheses and seeks correlation relationships between variables. Although this research can allow for more objective findings, one disadvantage is that findings, often in the form of mathematical averages, cannot capture the complexity associated with human behavior. When research is focused solely on numerical data it can miss the depth and detail assigned to phenomena by participants themselves (Creswell & Plano-Clark, 2010).

Alternatively, qualitative research seeks a deeper understanding of the social world. In the inquiry process, "qualitative researchers study things in their natural settings, attempting to make sense of, or to interpret, phenomena in terms of the meanings people bring to them" (Lincoln & Guba, 2000, p.3). Qualitative researchers focus on the development of theories based on an interpretive process. This requires that the researcher study the experiences, influences, and activities of research participants while acknowledging their own personal biases (Creswell & Plano-Clark, 2010). Qualitative research can suffer from this inherent bias and may privilege local understanding that is difficult to generalize.

In order to avoid focusing solely on numeric information or relying too much on the depth and detail assigned to phenomena by participants themselves, I used multiple stages and methods of data collection and analysis. This approach allowed me to get a better understanding of phenomena as I explored the research questions both quantitatively and qualitatively. By combining the reliability of empirical counts with the validity of lived experiences, mixed-methods research enabled me to provide a more robust set of findings, with greater reliability and validity. In this research I was able to rely on my own intuition and expertise to make decisions about when and how quantitative or qualitative data would be used. In addition, I used the process of peer debriefing to gather input and improve my research design. Therefore, I was able to approach different research questions by using a different combination and sequence of quantitative and qualitative analysis protocols. The specific analytical approach is discussed in detail within each of the data chapters focused on specific sub-questions of this research.

Over the past two decades mixed-methods research has grown and different approaches have been developed (Creswell & Plano-Clark, 2010). For example, some mixed-method designs use qualitative techniques to develop a theory that can be tested quantitatively, while other approaches use qualitative data to validate quantitative findings. In this dissertation, I first analyzed quantitative data, using descriptive statistics to empirically answer certain research questions and to generate emergent themes. Later in this chapter, I describe the overall design (summarized by a schematic diagram, see Figure 1). In the section that follows I discuss the theoretical perspectives that were used in this dissertation.

Theoretical Framework

The chapters in this dissertation span different periods of data collection, analysis, and application of theory. In order to focus the research, I introduce the specific theoretical frameworks within each chapter in the context in which they were used to analyze particular issues. This approach enables me to preserve results given the iterative process of research and evolving nature of research questions (Guba & Lincoln, 1989). The theoretical perspectives that were useful in this study include the structure/agency dialectic as it applies to implementing reformed science teaching (Sewell, 1999, Tobin & Roth, 2006), pedagogic leadership (MacNeill et al., 2005) and leadership content knowledge (Stein & Nelson, 2003), dimensions of leadership practice (York-Barr & Duke, 2004), and transformational teacher leadership (Leithwood, 1992; Pounder, 2006). Although each chapter emphasizes different theoretical perspectives, all of the chapters were influenced in some way by each of the theoretical perspectives, but the theory of structure and agency was a theoretical perspective that had a major influence on each chapter.

In this study, I use Sewell's (1999, 2005) theory of structure and agency as a lens to analyze the data. Sewell's conception of structure is used in social sciences to take into account human agency or power to act. Structures are made up of mutually sustaining schemas and resources, where schemas are rules or generalizable procedures and resources are human or non-human effects of schemas (Sewell, 2005). These structures “vary between indifferent institutional spheres” (Sewell, 1992, p. 16), making it necessary to consider how educational structures differ from other institutions and differ from each other. For example, the structures in an urban public school are likely very different than those within a private, independent school. Resources and cultural schemas are sustained by each other. For example, in a science classroom, the materials available to a teacher as well their beliefs about how best to teach science influences how the teacher acts. If a teacher possesses knowledge (i.e., a schema) about how to implement inquiry-based teaching and she can also access resources, she may or may not be able to transform her teaching, or be agentic. If she wants to enact the practices in order to meet her goals she will not only need to access the schema and resources, but she must also be able to appropriate or use them. For example, to be agentic she needs the structural supports in the school and classroom that will allow her to put her knowledge and material resources to use in order to implement inquiry-based teaching practices. If these structures are not in place to support her, then her agency may still be limited.

Agency, then, is the power to act (Tobin, 2008) to meet one’s goals. Because structure and agency are dialectically related, a person’s agency is tied to their ability to access and appropriate schema to meet their goals in any given moment in a social space (Tobin, 2008). For example, a science teacher may be interested in addressing an inconsistent science explanation of a particular phenomenon that her students bring to the classroom. Depending on her knowledge and beliefs about this she will act in a particular way. If she believes that alternative conceptions serve as a resource for building knowledge, she will act differently than if she views this as a deficit. Additionally, structural supports will influence her capability for action. In this dissertation, I examine structures—including schema and resources—in order to understand the ability of administrators and science teachers to access what is needed to enact leadership and reformed science education practices. I also examine their experiences in order to make sense of the structures that constrain or support them to appropriate these resources in order to meet their goals related to transforming science teaching and learning.

Agency is afforded when schemas are transposed and resources are remobilized in a unique way (Sewell, 2005). Rules (schema) about how to use these resources shape how successfully someone can do this. In all social spaces, such as a school or a classroom, there are various stakeholders (such as students, parents, administrators, etc) and each of these stakeholders can be said to be agentic as individuals and as a collective. Collective and individual agency of stakeholders in schools plays a role in the culture of the school for supporting teaching and learning and enactments of leadership practice. The ability to coordinate actions with or against others, such as working within a professional learning community (PLC) to analyze student work, is important when thinking about transforming schools through collective agency. In this dissertation, I examine the structures that constrain or afford agency, with regards to the implementation of reforms in science teaching and leadership practice. I characterize leadership practice with empirical examples of agency from the literature (described in more detail in Chapter 5). The lens of structure and agency is important for understanding how agency affects leadership practice that can build and sustain reforms in science education. Therefore, I have chosen to examine the structures that influence science teachers and administrators and how these structures affect administrator and teacher leadership practice, and in turn influence science pedagogy and a teacher's decision to stay in the classroom.

Structure and agency is also used as a tool for focusing my attention on possible constraints resulting from limited schema—knowledge and beliefs about science teaching and learning—and a lack of resources available to science teachers and administrators. In addition to this theoretical perspective, in Chapter 4, I use pedagogic leadership (PL) and leadership content knowledge (LCK) as frameworks for examining challenges, such as lack of resources and limited knowledge of science teaching and learning (schema), administrators face in supporting science teaching and learning. Pedagogic leadership is an approach to leading that considers how theory and practice intersect and ensures that educators have the time to reflect on their approaches, explore multiple perspectives, and consider moral implications of practice (MacNeill, et al., 2005). PL expands the notion of instructional leadership to include the leader as a reflective practitioner, and suggests that pedagogic leaders are empowered to exercise professional responsibility and have credible knowledge of teaching and learning (MacNeill et al., 2005). In this research, I focus on PL instead of instructional leadership because a focus on pedagogy provides a more inclusive view of all aspects of teaching, including the cultural, moral and societal aspects of what is learned and why it is learned. I analyze administrator leadership based on knowledge of teaching and learning science (LCK) and the ability to empower others in order to build collective action for reform (PL) because this combination is likely to be the best method for supporting reform-based science teaching and in turn improving student outcomes in science.

Using LCK and PL supports my focus on the goals of science education reform (discussed in detail in Chapter 4). In Table 1, I summarize the main components of PL and LCK and provide an overview of how I combine these lenses to frame my analysis with the concept of *reformed science leadership.*

Table 1

Framework for Reformed Science Leadership

Reformed Science Leadership	Pedagogic Leadership (PL)	Leadership Content Knowledge (LCK)
Focus on student achievement based on **knowledge** of science and how science is learned	Focus on students' learning	Focus on how students learn subject matter
Curriculum connected to national, state and local science standards and connected to authentic science problems	Curriculum determined by needs and interests of students and connected to examples drawn from real life/world	Curriculum connected to state and national standards
Predicated on **supporting** the science teaching profession based on knowledge about how teachers learn and teach science	Predicated on teaching as a profession	Predicated on knowledge about how teachers learn and teach subject matter
Promoting science teacher leaders	Distributed leadership	Principal as mentor
Building a **culture** of professional learning based on teaching and learning science	Building a professional learning community	Professional learning focused on coherent, subject-specific instructional guidance
Principal **actions** facilitate learning and evaluate effectiveness of approach based on knowledge of effective science teaching	Principal as leader of teacher professional learning	Principal equipped to observe and assess effective teaching
Moral, facilitative and **collaborative** in nature; Aims to support reformed science teaching	Moral and facilitative in nature	Collaborative and supportive in nature

Note. The information on PL was summarized from MacNeill, Cavanagh, & Silcox, 2005 and the information on LCK was summarized from Stein & Nelson, 2003

I used the categories (Table 1) to focus attention on the knowledge and actions of administrators to support science teachers to transform their practice by framing my analysis of administrator practice with the descriptions listed under reformed science leadership column.

Science teachers in this study displayed agency as science teacher leaders. In Chapter 5, I sought to describe this leadership practice (agency). In order to do this, I used the concept of leadership practice (York-Barr and Duke, 2004) to profile the roles of science teacher leaders. In the following section, I describe the seven dimensions of leadership practice, both formal and informal, based on empirical examples from the literature (see Table 2).

Table 2

Dimensions of Leadership Practice

Dimension of Practice	Example Teacher Leadership Activities
Coordination, management	Coordinating events, administrative meetings and tasks, monitoring
School or district curriculum work	Defining standards, selecting and developing curriculum
Professional development of colleagues	Mentoring other teachers, leading workshops, peer coaching, modeling/encouraging professional growth
Participation in school change/improvement	Taking part in school-wide decisions, facilitating PLCs, participating in research, challenging status quo
Parent and community involvement	Encouraging parent involvement, creating partnerships with community, working with community and community organizations
Contributions to the profession	Participating in professional organizations, becoming politically involved
Pre-service teacher education	Building partnerships with colleges and universities to prepare future teachers

Note: The information in this table was summarized from York-Barr and Duke, 2004

These leadership roles include instructional, professional development, and organizational functions, which I used to characterize the roles science teachers reported as leadership practice. In the section that follows, I introduce the concept of transformational science leadership as a lens for analyzing teachers' definitions of science leadership practice.

In addition to profiling teacher leadership practice, I also looked to the schematic resources teachers brought to their leadership practice. In order to describe their knowledge and beliefs about science teacher leadership I use the frameworks of transformational leadership and leadership content knowledge (LCK) to construct a framework for transformational science teacher leadership. Transformational leadership focuses on the commitments and capacities of organizational members for continuous improvement (Leithwood & Duke, 1999). Leithwood, Jantzi, & Steinbach (1999) describe transformational leadership as leadership through collective action that empowers those that participate in the process. Transformational leadership facilitates a redefinition of mission and vision and a renewal of commitment by all stakeholders, as well as a restructuring of systems to meet goals. Leadership content knowledge (LCK), similar to the idea of pedagogical content knowledge (Shulman, 1987), is the knowledge of the subject, how it is learned (by adults as well as students) and how it is taught that is used by instructional leaders (Stein & Nelson, 2003). Transformational leadership and LCK are typically used in education to describe the building principal but I extended these frameworks by using them to analyze science teacher leadership practice. Transformational science teacher leadership is collaborative, focused on authentic learning experiences for students connected to national, state and local standards, promotes inquiry-based teaching and empowers stakeholders (administrators, other teachers, students) to participate in pedagogic change. I describe these frameworks and how they were used in my analyses more extensively in Chapters 4, 5, and 6. In the section that follows, I provide an overview of the study, including the context, description of the participants, and overall research design.

Context of Study

This study explores these questions within longitudinal professional development programs for teachers and administrators in federally-funded Math-Science Partnership (MSP) programs designed to enhance teacher content knowledge and the knowledge of science education research of both teachers and administrators in order to transform practice in 5–12 schools.

MSP 1 – the NSTP. The first MSP, which I refer to as the NSTP, is a collaborative initiative between the university's Chemistry, Biology, Earth & Environmental Science, Mathematics, Physics and Astronomy Departments and the Graduate School of Education. The MSP consisted of two programs—one designed for high school science teachers and the other designed for middle grades (5-9) science educators. The goal of both programs within the MSP was to provide in-service teachers with content knowledge, science education theory and model instructional strategies in order to encourage teachers to implement reform-based teaching practices in their classrooms. Additionally, another outcome expected by program administrators was that the graduates would become teacher leaders in their schools and/or districts. Teacher leadership refers to teacher-participants working collaboratively with their colleagues to share their new pedagogical and content knowledge gained from participation in the NSTP (Blasie & Kahle, 2009). In this five-year funding period, the program added this leadership component, focusing on increasing knowledge of the administrators of teacher-participants, expanding distributed leadership practices and developing teacher leadership potential.

The professional development program consisted of 10 courses, eight on science content knowledge and two focused on the theory and practice of teaching and learning science. The duration of the program was 26 months and consisted of three full-time summer and two academic year sessions, when teachers are enrolled in two courses per session (see Table 3 for an overview of the program).

Table 3

Overview of the NSTP

	Schedule	Coursework	
Summer 1	8 weeks 9am – 3pm	Science Content Course	Science Content Course
Academic Year 1	2 Saturdays per month 8am – 2:30pm	Science Content Course	Science Education Course
Summer 2	8 weeks 9am – 3pm	Science Content Course	Science Content Course
Academic Year 2	2 Saturdays per month 8am – 2:30pm	Science Content Course	Science Education Course
Summer 3	8 weeks 9am – 3pm	Science Content Course	Capstone Course
Exit Projects	E-Portfolio	Content Exam	Thesis

In the summer, teachers were on campus Monday through Thursday and they attended courses on alternate Saturdays during the academic year. Successful graduation from the program required completing each course with a final grade of "B" or higher, passing a final science content examination based on growth of as indicated from scores on a pretest and posttest, writing a thesis within a science discipline, and receiving a score of "Pass" or "Exceeds Expectations" on all components of an electronic portfolio (e-portfolio) exit project.

Participants in the NSTP. Over a ten-year period (2000-2010) this MSP enrolled approximately 400 teacher and administrator participants, representing large urban, suburban, and rural school districts. In this dissertation, I report on years 6-10 (2005-2010) of the program, when administrators began to play a more integral role. The participants in the study included the 182 teachers who participated from 2005-2010. Approximately half of the 182 teacher participants served student populations from Title 1 schools, or those schools impacted by Title 1 of the US Department of Education Elementary and Secondary Act.[8] Furthermore, participants represent diverse school settings including public, private, parochial, and charter schools from five northeastern states. In Table 4, I provide descriptive data about my sample of teacher participants from the NSTP.

Table 4

Description of Teacher Participants in the NSTP

Gender	Average Age of Teachers	Demographics of Teachers	Description of School Context
42% male 58% female	35 years old	~25% underrepresented minority (13.5% African/African American 5% Asian 3% Indian American 1.5% Hispanic)	46% urban 45% suburban 7% rural 2% independent

[8] Title 1, Part A (referred to as Title 1) of the Elementary and Secondary Education Act provides financial assistance to local educational agencies and schools with high numbers or high percentages of children from low-income families.

Although the NSTP program took place over 10 years, during the last five years of the program, an Administrators' Science Institute (ASI) was introduced to better support teacher participants enrolled in the program. The ASI was developed in response to ongoing program evaluation, consistent with current research, which demonstrated that teacher participants lacked administrative support necessary to implement reform science teaching practices in their classrooms. This dissertation is focused on 54 administrator participants in the ASI (see Table 5 for an overview of the sample). A primary goal of the ASI was to provide professional development for building level administrators in science education research, to work with hands-on science materials in a research-based teaching and learning environment, and to work with other administrators on leadership issues associated with improving science education in their schools. The ASI took place over six sessions, three summer days and three Saturdays during the academic year (fall/winter/spring). The sessions lasted all day (8:30am – 4pm) and were designed to include pre-reading assignments, discussions of the readings, and active participation in science lessons and/or evaluation of these lessons. All ASI participants observing portions of NSTP classes that their teachers were enrolled in as well as interactions with their teacher partner as the teachers planned and carried out new teaching and learning strategies and action research projects.

Table 5

Description of Administrator Participants

Gender	School Context	Role
50% male	50% urban	38.9% district level supervisors & curriculum
50% female	44.5% suburban	coordinators
	2% rural	29.6% principals
	3.5%	11.1% science department chairs
	independent	7.4% assistant principals
		13% others

MSP 2 – the IBT. The second MSP, which I refer to as the Institute for Biology Teachers (IBT), was a collaboration among a private, Midwestern university, field trip sites, such as the local zoo, and the city public schools. This unique collaboration worked together to establish the advanced degree program and leadership training for teams of high school biology teachers. The IBT was designed to enhance content knowledge and pedagogy, through a blend of life sciences research and content and science education research and methods. It consisted of two, three-week summer institutes at the university focused on disciplinary content and online coursework during the academic year focused on pedagogical strategies for incorporating new content into teachers' classrooms (see Table 6 for an overview of the program). The program also aimed to develop science teacher leaders. To this end, the program instituted a leadership program, which continues to engage teachers upon graduation.

Table 6.

Overview of the IBT

	Schedule	Coursework		
Summer 1	3 weeks (1 week per course)	Science Content	Science Content	Science Content
Academic Year 1	Online, asynchronous	Science Content and Pedagogy	Case Studies	Program Capstone I
Summer 2	3 weeks (1 week per course)	Science Content	Science Content	Science Content
Academic Year 2	Online, asynchronous	Science Content and Pedagogy	Laboratory Investigations with Model Organisms	Program Capstone II

Participants in the IBT. Over a five-year period (2007-2011), IBT enrolled 77 teacher participants, representing urban, suburban, and rural school districts from all over the United States (see Figure 7). Criteria for selection included certified teachers with at least three years teaching experience, some leadership experience and/or leadership potential. The stated goals of the program were to develop a national cadre of master teachers who demonstrate intellectual engagement with, and master of, global issues in life science, and who use related research-based pedagogy and challenging content in their courses. The program also sought to promote partners' and participants' development as local and national educational leaders. Table 7 summarizes the teacher participants in the IBT.

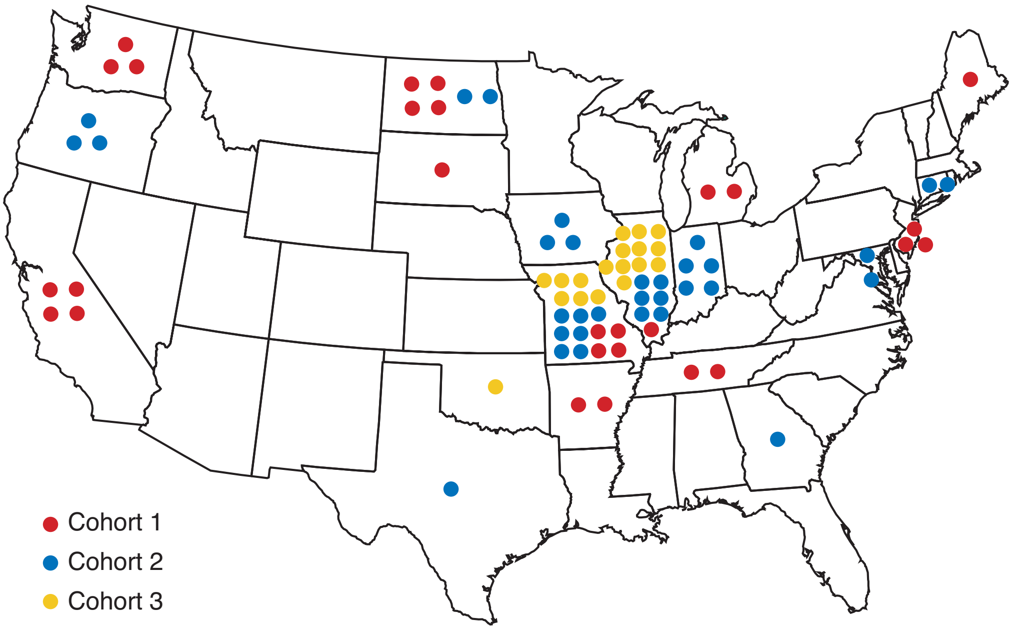

Figure 7. Geographic distribution of teacher participants in the IBT

Table 7

Description of Teacher Participants in the IBT

Gender	Average Years of Experience	Demographics of Teachers	Description of School Context
42% male 58% female	8 years	~ 16% underrepresented minority (6.5 % African American, 1.6% Asian 3.2% American Indian 4.8% Hispanic	Average school size of 1500 students Student population averages: 58% White non-Hispanic 7% White Hispanic 1% American Indian 6% Asian 27% African American

In this dissertation, I focus on four teacher-participants who were involved in a collaborative leadership project at the site of IBT during the summer of 2011. These teachers represent different school types (public and private, urban and suburban) from across the United States with 5-13 years of teaching experience. I selected these teachers as a representative sample because they exemplified the science teacher leader who is the subject of this dissertation. I draw from this group of participants for my data analyses in chapters 4 and 5.

I drew my sample of participants from the NSTP (n = 182), ASI (n = 54), and IBT (n = 4) programs. Within each program, I selected specific years of the program related to the availability of data and the research questions that focused the dissertation. Figure 8 provides a schematic overview of my sample. The schematic shows all of the programs and the corresponding participants and data sources used in the dissertation.

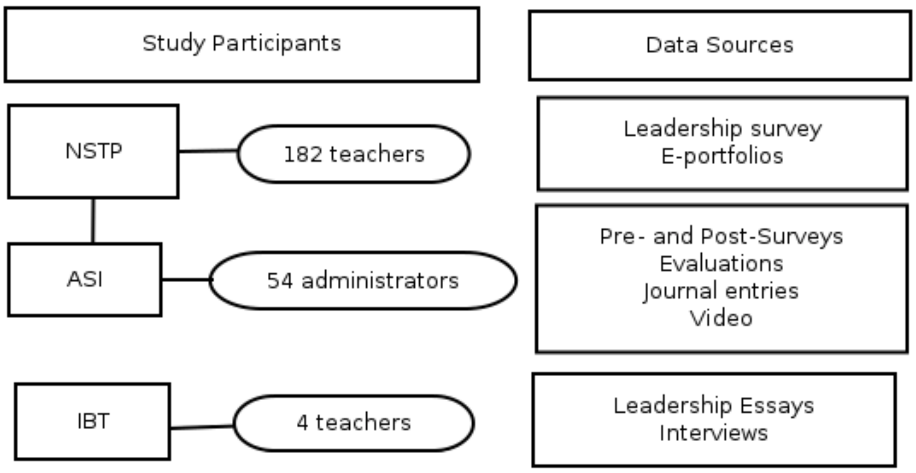

Figure 8. Schematic overview of sample. Diagram provides a summary of participants from the two MSP programs and data resources for this study

In the section that follows I provide a comprehensive overview of the study.

Study Overview

The overall design of this mixed-methods research is depicted by Figure 9. This diagram recognizes that the research questions were developed and the theoretical frameworks selected prior to beginning the quantitative analysis. Based on the theoretical framework, quantitative analysis, utilizing descriptive statistics, was used in order to provide empirical evidence that was used as a foundation for the themes that were further developed with the qualitative analysis. In order to explore the impact of the ASI on administrators (Chapter 4) and categorize teacher leadership roles (Chapter 5), I used a quantitative approach. In these cases, I used my theoretical frameworks to guide me as I grouped questions and calculated gain scores and categorized open-ended responses. Subsequently, I reanalyzed survey data and additional evidence, such as e-portfolios, journals, interviews, and video, using qualitative analysis to validate the results and further develop themes (Chapter 4 and 5). Additionally, I relied on qualitative analysis in order to answer particular research questions that led me to identify the structures that constrain and afford teacher leadership practice (Chapter 6). In my qualitative analyses, I rely on data triangulation to check and establish validity of my findings. I describe the specific research design in more detail within each individual data chapter.

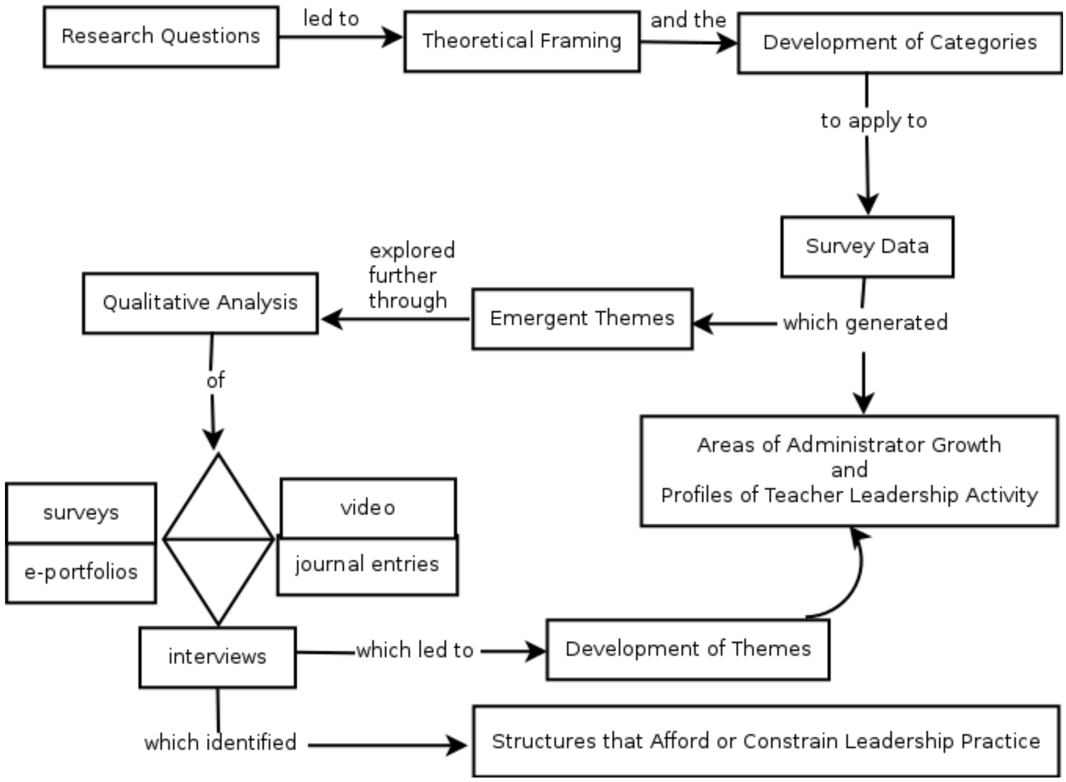

Figure 9. Schematic diagram describing overall research design.

Sources of Data

In this section I describe each data source collected and analyzed (see Figure 8) in order to answer the chapter-specific research questions. Table 8 summarizes the specific context of the data sources and outlines the chapters, which draw from this data.

Table 8.

Data Sources for Study by Chapter

Data Source	Context	Ch 4	Ch 5	Ch 6
Pre- and post-surveys	ASI	X		
Video of sessions	ASI	X		
Session evaluations	ASI			
Electronic portfolios	NSTP	X	X	X
Journal entries	ASI	X		
Leadership survey	NSTP	X	X	X
Application essays	NSTP and BTI		X	X
Interviews	BTI		X	X

Pre- and post-survey. Prior to participating in the ASI, administrators were given a survey to gauge their knowledge and actions related to science education reform and leadership practice. Post-surveys were administered to administrators who participated in sessions. Data from these surveys were analyzed from those administrators who completed both the pre- and post-surveys. The topics of the survey corresponded with what literature suggests leaders in science education should know and do in relation to teaching and learning science. I created subsections with the survey questions and calculated gain scores using dependent (paired) t-tests in order to find out areas of significant growth based on participation in the ASI.

Video of sessions. Select sessions of the ASI were videotapes. I specifically analyzed video of sessions focused on ASI session learning experiences centered around building administrators' conceptual understanding of inquiry-based science teaching. In addition, I transcribed video of group discussions where administrators described strengths and challenges for supporting science teachers in their efforts to implement reform-based teaching in their classrooms.

Session evaluations. After each ASI session administrators were asked to evaluate the experience. In addition, at the end of the cumulative experience, administrators reflected on the sum total of the experience. These evaluations were used as documentary evidence for the influence of the ASI on administrator knowledge and actions.

Electronic portfolio (e-portfolio). The e-portfolio was a high stakes assessment that was added as a degree requirement to NSTP in 2005. Teacher participants were required to use the e-portfolio to demonstrate their growth as a result of having participated in the program. It was required that participants use appropriate baseline and corresponding post-baseline evidence explain and depict growth within all e-portfolio rubric item entries (e.g., what the evidence was, why it was chosen, and how it illustrates growth). Thirty-six e-portfolios entries with supporting evidence were analyzed in Chapter 5 to provide evidence for teachers' definitions and perceptions of leadership practice. These entries were also used in Chapter 4 and 6 to look at specific hindrances and affordances to leadership practice and explore the influence of the administrator on teacher agency.

Leadership survey. During their participation in the NSTP, teachers reported their leadership activities on online leadership surveys during Years 1 and 2 of the program and graduates completed an exit survey. The survey included categories of leadership: facilitating, presenting, coaching/mentoring and consulting, based on the project directors' appraisal of these activities as "high impact" transformational leadership practice. The leadership survey, developed by project leadership for internal program evaluation, included ten questions that asked teachers to select which of the above leadership practices in which they participated. Additionally, two questions were open-ended, which asked teachers to describe their leadership activities (Kahle, Li & Scantlebury, 2010). This research focuses on three survey questions in order to characterize the roles that teachers play in their schools and districts and describe the ways they define leadership practice based on the seven dimensions of leadership practice (York-Barr & Duke, 2004) and the additional codes: science pedagogical content knowledge, definitions of teacher leaders, role of administrator and influence of the MSP.

Leadership application essays. Both the NSTP and BTI required teachers to apply to the program and asked teachers for information about their ideas about leadership, including examples of how they have exhibited leadership. In the NSTP, teachers used excerpts from their application essays in their electronic portfolios to demonstrate how their definitions of leadership and involvement in leadership activities had changed. In the BTI, teachers were asked to select a leadership theory they most identified with and write an essay about why they selected this leadership theory and how they experienced this leadership in the daily life of teaching. These leadership essays were analyzed using inductive means in order to characterize teachers' definitions of leadership. In order to describe teachers' definitions of science leadership, the framework of transformational science leadership was applied.

Interviews. The IBT provided teachers the opportunity to develop leadership projects. One such project brought together five teachers, representing five different states, who introduced case studies into their teaching plan (2007-2009) to practice teaching and improve on their cases. This program transcended the boundaries of their classrooms as they worked collaboratively with their colleagues as both teacher and learner. Teacher interviews were administered using a semi-structured interview protocol prior to participation in the collaborative case-study professional development and upon completion of the program. Additional interviews were completed with teachers using questions intended to probe leadership practice.

Data Collection and Analyses

I used purposeful sampling driven by my theoretical frameworks in order to make decisions about what data to collect and analyze. This approach allowed me to uncover the full array of multiple perspectives, without suppressing contradictions (Lincoln & Guba, 1985). Because the funding agency (NSF) required on-going internal and external evaluation of both MSPs, all participants completed validated surveys periodically. These surveys measured participants' leadership activity, and knowledge and beliefs about science teaching and learning. I used surveys and subsets of questions as the foundation for the deductive analysis that in turn leads to themes to explore inductively. As I assimilated early assertions with quantitative data, I moved toward sampling based on theoretical relevance. This approach allowed me to saturate the themes and demonstrate the range or variation of each theme across different situations and in relation to other concepts in order to make it theoretically meaningful. In addition, I used discriminate sampling to gather data until no new relevant data were discovered regarding a category and the categories were well developed and validated. This process led me to include data from both the NSTP and the IBT in order to enhance the possibility of comparative analysis. In addition, I subsequently conducted interviews of a small subset of teachers from the IBT who were selected because they represented the science teacher leader who is the subject of this dissertation. I include these data in Chapters 5 and 6.

My analytic approach included the analysis of pre- and post-survey results, which I grouped into five subsections related to the main tenets of my theoretical frameworks. After creating subsections with the survey questions, I calculated gain scores and ran dependent (paired) t-test on the gain scores for each. For the subsections where the gain was statistically significant qualitative data was used to further explore these themes. I discuss this in more detail in Chapter 4. My qualitative data analysis involved multiple stages and levels of coding using a cross-platform app for analyzing qualitative research called Dedoose[9] (see Figure 10).

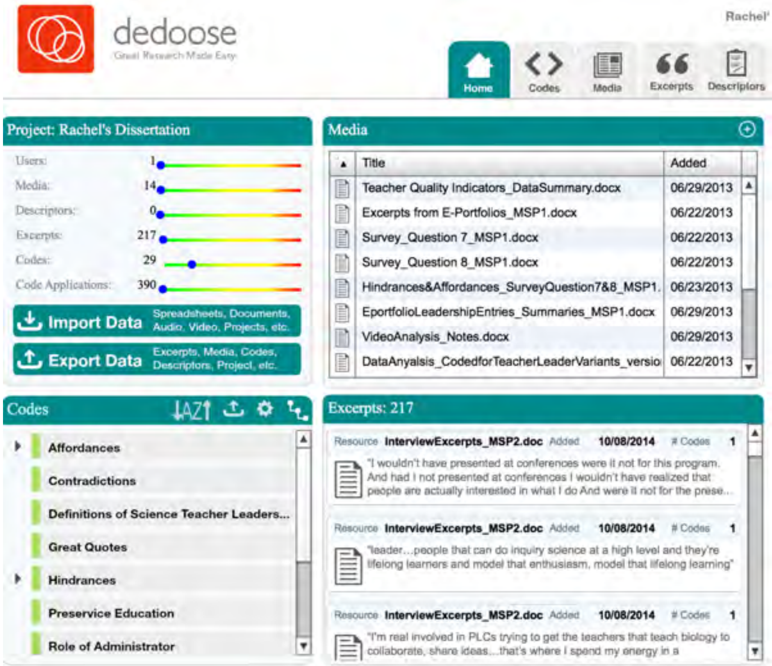

Figure 10. Screenshot of project in Dedoose.

I coded data based on the themes from the quantitative analysis while allowing for emergent themes. I then used empirical coding to tag each coded excerpt with a nested code based on sub-themes that presented as patterns in the data. I discuss the specific qualitative approach and findings from the analysis in more detail in Chapters 4, 5, and 6. This allowed me to uncover and explore the themes based on the lived experiences of participants using several sources of data to corroborate my findings. While this provides a general overview of my approach to collecting and analyzing the data, the specific analytical approach is described in more detail in the individual data chapters (4, 5, and 6).

Limitations and Delimitations

This dissertation did not focus on all administrators and all teachers, but rather I chose to study a specific population—those engaged with MSP programs.

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[9] Dedoose (www.dedoose.com) is a cross-platform app for analyzing qualitative and mixed methods research with text, photos, audio, videos, and spreadsheet data.

This allowed me to examine the influence of these programs on those that self-selected to participate in a program focused on promoting science education reform. By studying this particular group I was able to explore the influence of the MSP on this group as well as better understand how these teachers and administrators, who are invested in science education reform, might still experience challenges that make it difficult for them to realize their goals.

The dissertation suffers from some of the limitations of exploratory research. This study was limited to a small study with selected participants—those who would apply and be admitted to programs at prestigious universities. The teachers were already likely leaders in their own buildings and further developed through their participation in the MSP programs. The administrators were selected by the teachers to participate in the program. Therefore, the administrators were more likely to be those who had some science knowledge or with good relationships with the teacher participants. This limitation narrowed the scope of the work such that I could consider how these MSP programs influenced this group of teachers and their administrators and explore the particular challenges they faced.

A second limitation was the data available. The two MSP programs were developed independently. Therefore, while the funding agency required on-going internal and external evaluation, the specific surveys and other documentary evidence differed. Although the data collected from the two programs was different, the combination of the data sources collected through the MSP programs provided enough information to garner insight into the important issues in this dissertation. Access to limited data shaped the research questions by sharpening them so they could be answered by the available data. This strengthened the dissertation by providing focus to the work and leaving other questions that surfaced as topics for further research

Another limitation to the data was that administrators and teachers were limited by prompts for surveys, journals, leadership essays, interviews and e-portfolio rubrics. For example, the e-portfolio rubric provided examples of leadership activities, which many teachers used in their e-portfolio reflection. Furthermore, administrators and teachers provided answers to the given survey questions. This was important because analyzing the interpretation of the questions provided insight into how structures of the MSP program influenced the administrators and teachers in the programs.

Conclusions

This mixed-methods study was designed to allow me to explore my research questions using both quantitative and qualitative data in order to better understand the role of administrator and teacher leadership in science education reform. Although each data chapter that follows relies on a slightly different theoretical framework, the overall study is grounded in the theoretical perspective of the structure and agency dialectic. In the following chapters, I introduce the specific theoretical frameworks within each chapter in the context in which they were used to analyze particular issues in order to maintain the authenticity of results, given the nature of the complex research process. Overall, this research combined the reliability of empirical counts with the validity of lived experiences to provide a more nuanced understanding of the phenomena under investigation.

In the following chapters I share my findings on the impact of the MSP programs for administrators and science teachers on leadership practice. I also provide a summary of the challenges that teachers and administrators face as they tried to implement science education reform. The mixed-methods design of this research allowed for these issues to be better explored by combining different methods and techniques. While all research designs have limitations, the insights that emerge have implications for science teacher education and designs of K-12 schools that support leadership that promotes science education reform.

CHAPTER 4 – CHALLENGES AND OPPORTUNITIES: HOW CAN DISCIPLINE-SPECIFIC PROFESSIONAL DEVELOPMENT HELP ADMINISTRATORS TO SUPPORT REFORMS IN SECONDARY SCIENCE EDUCATION?

Introduction

With the release of the Next Generation Science Standards (NGSS), science teachers are being asked to refocus their K-12 teaching in order to improve college preparation, STEM career readiness, and students' ability to make informed decisions. The conceptual shifts in the NGSS seek to promote a new vision for science education and transform the way science is being taught in many classrooms. Implementing the NGSS will require that teachers make a significant shift in the content and manner in which they have been teaching. Despite evidence that the classroom teacher plays a critical role in student success (e.g., Darling-Hammond, 2000; Johnson et. al., 2007; Wright, Horn, & Sanders, 1997), there are other players that influence the teaching and learning of science in schools. Administrators,[10] especially principals,[11] are faced with having to make sense of the new standards and provide instructional leadership that supports and promotes this shift in science teaching and learning.

Well-informed principals are essential to fostering the changes necessary to support visions of effective science teaching and learning according to the NGSS. Principals should be knowledgeable about the content and quality of the educational program in their schools and with the processes that support their successful implementation. As science education policy continues to evolve, the actions of principals supporting these innovations in curriculum and pedagogy become increasingly important. This is because the extent to which teachers are supported to implement reform science teaching practices is dependent, in large part, upon the administrative practices of district and building level decision makers (Leithwood, Seashore, Anderson, & Wahlstrom, 2004). Until recently, there has been little research examining the principal's role in student success. Some research suggests that principals are second only to teachers in their impact on student achievement

[10] The term administrator refers to those holding formal leadership roles in school districts, including superintendents, curriculum supervisors, and building principals.
[11] In this paper, the term principal is used to indicate a building level leader of a particular school. This person may also be referred to as school leader, head of school, headmaster or school director.

(Wallace Foundation, 2012). The shifting role of the principal from building manager and student disciplinarian, to instructional leader to learning leader, suggests that effective principals are responsible for student learning (McHatten et. al, 2010; Wallace Foundation, 2012).

Policymakers and school reforms insist that the role of the principal, particularly at the secondary level, is that of an active agent in the teaching, learning and implementation of curriculum and instruction (Boscardin, 2005). Principals dedicate much of their time to solving instructional problems that arise in schools and facilitating improvements in instructional practice. Since the late 1980s, national and international assessment data have highlighted the need for improvement of instruction in the sciences (Fleischman et al., 2010). Based on their performance on the National Assessment for Educational Progress (NAEP) and the Program for International Student Assessment (PISA), students in the United States, lag behind students from other technologically advanced countries in science. These assessments measure student achievement in science content knowledge, science practices and scientific literacy. While the state of science achievement in the United States would suggest that science requires more attention from school principals, currently, with the exception of a recently published study (Oliveira et al., 2013), there is little research published about the role principals play with regards to supporting science education. However, the study's findings are significant in that researchers found when principals are efficient in directing efforts to improve science education through the use of data and dialogue, curriculum revision work, and support of recommended instructional approaches, it can lead to improved student achievement and success (Oliveira et al., 2013). Yet, while principals have the potential to be a key lever for science education reform, little is known about what they need to be effective leaders (Elmore, 2007; Levine, 2005).

This study seeks to add to the research base on the role of the principal in the teaching and learning of science by reporting on results of a study focused on an Administrators' Science Institute (ASI), part of a federally-funded Math-Science Partnership (MSP) institute in the northeastern United States. The MSP institute was designed to enhance teacher content knowledge and the knowledge of science education research of both teachers and administrators in order to transform science practice in secondary schools. I examine the impact of administrators' participation in ASI, a professional development program in the MSP, on changes in administrator's content-specific leadership necessary for supporting the teaching and learning of science. I also report on the challenges faced by the administrators of teachers in the MSP program as they participated in the ASI and attempted to support their science teachers to enact reform-based inquiry teaching in their schools. I offer implications for the design of science teacher and principal in-service professional development and I raise questions for future research in this area. In the following section, I offer a brief overview about administrator demographics and preparation to provide context for the challenges they face in supporting reforms to science education at the K-12 levels.

Literature Review

This paper focuses on administrators, especially building principals, in the United States. According to the Schools and Staffing Survey (NCES, 2012) conducted by the National Center for Education Statistics of the Institute of Education Sciences, the average public school principal has been at their current school for approximately 4 years. Demographic data show that overall, there are about equal percentages of female and male public school principals, but there are differences when disaggregating data by secondary or elementary with more female elementary school principals (63.8%) and more male high school principals (59.9%). The private school principal population is smaller overall and shows a few noteworthy differences from the public school principal. For example, private school principals tend to have a lower average salary, a greater number of years of experience, and fewer higher education degrees. The distribution of principals by race mirrors the teaching force with a few exceptions. One difference is that while Black teachers represent 6.8% of the teacher workforce, they represent 10.1% of the principal population. This may be due to racial differences in preferences for pursuing school leadership positions, differences in access to mentoring as a result of different social networks, and increased opportunities for informal recruiting for Black teachers (Williams, 2012). In the following section, I describe in greater detail common pathways for becoming a principal in the United States and a summary from the research about what administrators know about teaching and learning science.

Administrators' Teaching Experiences

Nearly all principals were former teachers. In fact, data from the School and Staffing Survey found that 98% of principals were teachers before they became principals, teaching an average of 10.6 years (NCES, 2012). This means that virtually all public school principals have some classroom level teaching experience, although it is unlikely they have experience teaching across multiple content areas. Principals who taught in elementary school may have experience across several grade levels and content area. However, a common practice in elementary schools is for teachers to specialize in one or two content areas, meaning a teacher may be responsible for teaching only math and science or only social studies and English Language Arts (ELA). During a 10-year teaching career, a teacher is likely to concentrate on a specific grade level or small range of grade levels, thus, principals at the elementary level likely do not have expertise in each content area and grade level. At the secondary level, it is even less likely as content certifications are more specific, meaning a teacher certified in math or English would have limited teaching experiences in science content areas. The data show that only 11% of all public school teachers are science teachers so assuming science teachers become principals at the same rate as other teachers, we can conclude that about 90% of principals do not have specific content or pedagogical expertise or teaching experience in science. This is significant because research suggests that a principal's views of subject matter shape their ability to lead pedagogical change (Burch & Spillane, 2003; Stein & Nelson, 2003) and with the majority of principals having limited expertise in science content, principals likely face many challenges in their attempts to support the implementation of innovative science curriculum and reform teaching practices aligned to the NGSS. Thus, principals would primarily be expected to rely upon the preparation they receive from principal education programs as means for building their capacity to lead science teachers, but there is little to suggest they are receiving content specific instruction.

Preparation and Professional Development for Administrators

To become a principal in a public school in the United States, most states require that candidates hold a master's degree in education administration or leadership (NCES, 2012) and a pre-requisite for many such degree programs is a bachelor's degree in education, school counseling, or a related field (US Department of Labor, 2014). However, some states have alternative programs, focused on preparing candidates with successful experiences in leadership, supervision, upper-level management or other positions in business, corporations or the military. These programs do not require specific education related coursework or teaching experience. Most states require public school principals to be licensed as school administrators, although this does not apply to principals in private schools. Administrators in many states are also required to take continuing education classes to maintain their license.

Traditionally the preparation of school principals has focused on understanding organizational conditions that support high quality teaching and learning, such as promoting high expectations for student learning, facilitating a positive school climate, and decentralizing decision making (i.e., distributed leadership). A report called Educating School Leaders (Levine, 2005) analyzed university-based programs that educate the majority of administrators in the United States and the report criticized these programs for not meeting the demand of preparing administrators to lead student learning (Levine, 2005). Unfortunately, little is known about the knowledge administrators need to be effective leaders and researchers have called for increased practice-based research in school administration (Elmore, 2007; Levine, 2005). Considering that effective leadership plays a pivotal role in how a subject is taught, ensuring appropriate preparation and in-service support, including foundational knowledge of subject-specific pedagogy and content, is extremely important. With a shifting role of the principal from manager to instructional leader, some principal preparation programs and professional organizations have attempted to respond by creating standards (Grossman, 2011). However, most professional development programs for principals are not context specific, provide little content-specific training, and have shown to be ineffective in affecting change (Boyd, et al., 2009). In this paper, I focus my attention on the need for administrative leadership in the area of science teaching and learning. In the section that follows I discuss challenges administrators face as they seek to support science teaching and learning in their schools.

Administrators Face a Variety of Challenges

School principals in the United States face numerous challenges and data suggests that the job is becoming more complex and stressful. With the introduction of national standards and accountability, school principals face challenges of finding and allocating resources, ensuring professional learning necessary for meeting new standards and facilitating changes in curriculum and instruction. State accountability systems place the burden of student achievement almost entirely on the school principal (Bottoms & Schmidt-Davis, 2010). Principals take on this burden with 89% of principals believing that they should be held accountable for everything that happens to children in a school (Markow, Macia, & Lee, 2013). The growing challenges contribute to annual turnover rates for principals that range between 15 and 30 percent (NCES, 2012). Although this is similar to turnover rates of managers in other professions, the turnover rates at schools with more challenges, such as high poverty schools, are on the higher end of this spectrum (Hull, 2012).

While principals are being held accountable for the functioning of the schools, they have little decision making control regarding school finances and they face diminishing school budgets with continual annual declines (Markow, Macia, & Lee, 2013). This is especially true in districts with the most struggling schools, as new austerity budgets are passed by state legislatures. For example, Philadelphia city school district faces an $81million deficit at the time of this writing (Associated Press, 2014). This has led to the closing of 24 buildings, forced relocation of thousands of students to unfamiliar schools, and the elimination or furloughing of staff members, including guidance counselors and secretaries (Hurdle, 2014). Declining school budgets are associated with a decrease in collaboration time and professional development opportunities (Markow, Macia, & Lee, 2013) with an overall deterioration of the professional learning environment.

Principals are ultimately responsible for setting the learning environment of their building, including the professional learning environment focused on continued learning and professional inquiry. This is challenging because principals spend much of their time managing day-to-day operations and handling other immediate concerns. In the area of instructional improvement, principals place greatest importance on being able to use data about student performance to develop teaching capacity across a school. Importantly, many principals also do not have the knowledge and skills required to effectively implement teacher evaluation systems and only about 40% of principals say they have decision-making capacity to hire or fire teaching staff (Markow, Macia, & Lee, 2013).

Administrators Views on Science Teaching and Learning

Because principals serve as the arbiters of instructional quality in their schools, classroom observation and teacher supervision are central to instructional improvement. Research in the area of mathematics has shown that principals' understanding of high quality instruction and ideas about how they can support it are influenced by their knowledge of math and beliefs about nature of mathematics learning and teaching (Nelson, 1998, Spillane & Halverson, 1998, Stein & Nelson, 2003). These findings provide strong evidence that knowledge and beliefs about science teaching and learning likely play a key role in how principals observe science classrooms, judge quality instruction, and interact with their teachers about science teaching. Having leadership content knowledge in science would allow principals to recognize strong instruction when they see it, encourage teachers with specific strategies when they do not see it, and promote a culture suitable for reformed science teaching.[12] Understanding what principals know and believe about reformed science teaching and learning and how it informs administrator practice can influence the way that science teachers are supported to teach science.

Research Design

In this study I share key areas of growth as well as specific challenges that emerged as administrators participated in a professional development program (ASI) focused on fostering the knowledge and skills necessary to support shifts associated with reformed science teaching and learning. Using an interpretive research paradigm, the researchers seek to provide a detailed, descriptive account of the knowledge and actions of administrator participants. The following questions guided my analysis of data:

1. What impact does a professional development program for administrators have on administrators' leadership content knowledge and pedagogic leadership with regards to science teaching and learning?
2. What challenges do administrators face in supporting science teaching and learning?

[12] In this paper, I use reformed science teaching to represent the pedagogy promoted by the MSP. Reformed science teaching aims to be consistent with the nature of scientific inquiry, reflects scientific values, requires the use of data to justify positions and takes its time to ensure students learn deeply.

Both researchers in this study were longitudinally connected to the program. Both researchers served as classroom science teachers and graduated as teacher participants from the MSP degree programs. Later, both researchers served as program evaluators and facilitators of the ASI program. As such, both researchers bring an emic perspective to this inquiry.

Theoretical Framework

To answer the questions in this study, I use pedagogic leadership (PL) and leadership content knowledge (LCK) as lenses for examining challenges administrators face in supporting science teaching and learning. Pedagogic leadership is an approach to leading that considers how theory and practice intersect and ensures that educators have the time to reflect on their approaches, explore multiple perspectives, and consider moral implications of practice (MacNeill et al., 2005). PL expands the notion of instructional leadership to include the leader as a reflective practitioner, and suggests that pedagogic leaders are empowered to exercise professional responsibility and have credible knowledge of teaching and learning (MacNeill et al., 2005). In this research, I focus on PL instead of instructional leadership because a focus on pedagogy provides a more inclusive view of all aspects of teaching, including the cultural, moral and societal aspects of what is learned and why it is learned. I analyze administrator leadership based on knowledge of teaching and learning science (LCK) and the ability to empower others in order to build collective action for reform (PL) because this combination is likely to be the best method for supporting reform-based science teaching and in turn improving student outcomes in science.

In order to be an effective instructional leader, research suggests that principals' LCK, or knowledge of the subject matter instruction regarding how it is best to teach and learn (science in this case), is critical (Stein & Nelson, 2003) for administrators to be able to support teachers (Spillane, Halverson, & Diamond, 2004). For example, previous research suggests that LCK for mathematics influences the way principals evaluate the adequacy of mathematics instruction during classroom observations. Studies show that instructional leadership has four times more impact on student achievement than leadership approaches where principals only focus on improving the morale of their teachers (Robinson, Lloyd, and Rowe, 2008). In higher performing schools, principals are more frequently involved in making classroom observations and providing feedback to teachers about their classroom teaching practices (Robinson, Lloyd, and Rowe, 2008). When principals monitor teachers and coach them to instructional improvement, administrators can promote reflective practice and increase teacher efficacy (Blase & Blase, 2000). However, studies have also found that the degree of subject specialization, especially at the secondary level, can serve to exclude a specialist in another subject from making more than general comments about their teacher's lessons (MacNeill et al., 2005). This finding suggests administrators with LCK also benefit from having pedagogical leadership (PL).

Using LCK and PL supports my focus on the goals of science education reform—including scientific and technological literacy for an educated society, improved approaches for achieving equity for all students, and better preparation of students for careers in the modern workforce (NAS, 2012). In Table 9, I summarize the main components of PL and LCK and provide an overview of how I combine these lenses to frame my analysis with the concept of *reformed science leadership.* I use the categories below to focus attention on the knowledge and actions of administrators to support science teachers to transform their practice by framing my analysis of administrator practice with the descriptions listed under reformed science leadership column.

Table 9

Framework Reformed Science Leadership

Reformed Science Leadership	Pedagogic Leadership	Leadership Content Knowledge
Focus on student achievement based on **knowledge** of science and how science is learned	Focus on students' learning	Focus on how students learn subject matter
Curriculum connected to national, state and local science standards and connected to authentic science problems	Curriculum determined by needs and interests of students and connected to examples drawn from real life/world	Curriculum connected to state and national standards
Predicated on **supporting** the science teaching profession based on knowledge about how teachers learn and teach science	Predicated on teaching as a profession	Predicated on knowledge about how teachers learn and teach subject matter
Promoting science teacher leaders	Distributed leadership	Principal as mentor
Building a **culture** of professional learning based on teaching and learning science	Building a professional learning community	Professional learning focused on coherent, subject-specific instructional guidance
Principal **actions** facilitate learning and evaluate effectiveness of approach based on knowledge of effective science teaching	Principal as leader of teacher professional learning	Principal equipped to observe and assess effective teaching
Moral, facilitative and **collaborative** in nature; Aims to support reformed science teaching	Moral and facilitative in nature	Collaborative and supportive in nature

Note. The information on PL was summarized from MacNeill, Cavanagh, & Silcox, 2005 and the information on LCK was summarized from Stein & Nelson, 2003

Methods

This study utilizes a three-phase mixed methods design by employing both quantitative analysis of data from a validated survey instrument and a qualitative analysis of administrators' and teachers' experiences within the context of their involvement within the MSP programs. In this study, quantitative survey data preceded the qualitative work. I use survey data to explore areas of growth in categories related to reformed science leadership. I then analyzed text data using multiple stages of data coding to further explore issues related to administrator growth. Then, I analyze data sources in order to provide an in depth view of the challenges administrators faced as they participated in the program. Finally, I use documentation of several collaborative action research projects to highlight contradictions and illuminate experiences of administrators in the ASI and their science teacher counterparts in the MSP program. Through an interpretive research paradigm I provide a detailed, descriptive account of the knowledge and actions of administrator participants before and after participation in ASI, as well as the challenges that transpired throughout program participation. As a former teacher participant in the MSP program, I bring an "insider's point of view" to my analysis of participant interactions and my close exploration of several sources of data from which I identified critical categories and emergent meanings.

Program description. ASI was designed to provide professional development for building level administrators to introduce them to science education research, to work with hands-on science materials in a research-based teaching and learning environment, and to work with other administrators on leadership issues associated with improving science education in their schools. ASI consisted of six sessions, three consecutive days in the summer session and three Saturdays during the academic school year (roughly once every three months). The administrators heard from experts in the field, completed readings and questions about the readings, and participated in inquiry-based science lessons and small and whole group discussions. During ASI, administrators had the opportunity to observe their science teachers in MSP program courses, informally connect during interactive lunch meetings with other administrators and teachers from their school, and engage in strategic collaborative projects with their teachers aimed at improving science in their own schools.

Participants - my sample. The participants in this study were 54 school and district leaders who participated in ASI from 2005–2009. Although ASI targeted building level principals with the idea that they can best support science teachers in their building, ASI included building principals (n = 16), science department chairs (n = 6), district level supervisors and curriculum coordinators (n = 21), assistant principals (n = 4), and others (n = 7). Those in the other category included teacher leaders, mentors, superintendents, and guidance counselors. Participating administrators were mostly from large suburban school districts (50%) and urban school districts (44.4%), with a single administrator from a rural district and two administrators from independent schools. About half of the administrators were from Title I schools. I focus on school principals, but include data from the district level administrators, department heads, and other leaders who participated in ASI.

Data sources. This research was conducted primarily by surveying administrator and teacher participants throughout their participation in the two programs. I also collected video of selected ASI sessions, which were transcribed. Additionally, I examined a large volume of documentary evidence, including journal entries, electronic portfolios, and documents evaluating ASI effectiveness (surveys completed by administrators and reports from external evaluators about the impact of ASI on teacher participants in schools). Administrators completed journal entries as part of their on-going monthly assignments and the teachers produced electronic portfolios as part of their summative assessment in the MSP program.

Data Analysis

Analysis of Phase I quantitative survey data was completed to learn more about administrators in the program and to analyze the effect of participation in ASI. The topics addressed in the survey correspond with what literature suggests leaders in science education should know about teaching and learning science, which also aligns with my theory of reformed science leadership. To analyze the pre-, post-survey results, I grouped survey questions into five subsections: *knowledge*, *action*, *support*, *culture*, and *collaboration*. These categories were selected because they relate to the main tenets in my framework (see Table 9). After creating subsections with the survey questions, I calculated gain scores and ran dependent (paired) t-test on the gain scores for each. For the subsections where the gain was statistically significant, qualitative data was used to further explore the identified themes during Phase II of the analysis.

In Phase II, I conducted analysis of video from sessions, interviews, field notes from observations of activities and visits to school sites, administrator journal entries, and other relevant documents. Phase II data analysis involved multiple stages and levels of coding (Strauss & Corbin, 1998) using a qualitative computer program, Dedoose. I began by coding the large volume of text data based on the areas where administrators demonstrated significant growth: *knowledge* and *action*. I then used empirical coding to tag each coded excerpt with a nested code, based on emergent themes. This allowed us to uncover and explore the specific ways in which administrators grew in these areas. I selected examples from each emergent category to showcase the improved leadership content knowledge (LCK) and pedagogic leadership (PL) actions of administrators that supported science teachers.

In Phase III, my research questions guided us to focus on administrator challenges and the influence of ASI in supporting reformed science teaching and learning. I began by searching my data for information related to challenges administrators faced. In this analysis, codes were not preconceived, but rather emerged from this data: *knowledge of science teaching and learning*, *self-efficacy for facilitating teacher growth*, and *isolation*. These categories fit within my theoretical framework because they focus on understanding the knowledge and skills administrators have to facilitate professional learning of teachers, support evaluation practices focused on actionable feedback and pedagogic change, and frequency and quality of collaborative interactions with teachers and peer administrators to reform science teaching aimed at improving student achievement. Within each of these three categories, I focused on perceptions of problems and changes in practice as envisioned by the administrators. In my analysis, I highlight the approaches ASI implemented to help address these challenges. I selected examples from my data to present as descriptive vignettes that both confirm and contradict the challenges reported in the literature. Validity of the analysis was improved by triangulation of the data sources, including survey data, video transcripts, journal entries, ASI evaluations and electronic portfolios.

Findings

In this section, I explore how ASI facilitated administrators' growth related to knowledge of science education reform leadership and how participation in ASI promoted change in administrator practices. I then draw attention to the challenges administrators faced as they sought to utilize the knowledge gained to enact practices to support reformed science leadership within their personal school contexts. I also highlight a contradiction to these challenges, which informs my discussion about the need to expand content specific professional development for administrators that promotes the ways in which they support implementation of reformed science teaching practices.

Impact of ASI on Administrators

I begin this section by showcasing the growth of administrators in terms of their knowledge and actions aligned to my framework of reformed science leadership as a result of participation in the ASI. I do this by first highlighting growth based on gain scores on pre- and post-surveys and then presenting categories of growth within these areas through subsequent qualitative analysis (see Table 10). Based on a dependent (paired) t-test of pre- and post-survey results, participation in ASI resulted in no statistically significant differences in the categories of support, culture, or collaboration. However, findings for the sub-sections of knowledge and action indicate the mean gain was statistically significant [$t = 8.33$, $df = 23$, $p < .001$ and $t = 4.85$, $df = 23$, $p < .001$, respectively]. The significant gain in knowledge and action led us to focus on these categories in my analysis. The fact that conditions for statistical significance were not met in the other categories leads us to believe that these areas were those that posed more significant challenges for administrator participants in their school and district contexts. I discuss these challenges in more detail in the sections that follow.

Table 10.

Descriptive Statistics for Survey Sub-sections

Sub-section	Mean	SD	Std. Error Mean
Knowledge	5.90	3.46	0.70
Action	5.25	5.30	1.08
Support	1.41	3.76	0.77
Culture	0.75	3.70	0.75
Collaboration	0.46	3.54	0.72

ASI improved administrator knowledge about reformed science leadership. One of the goals of the ASI was to help administrators become more familiar with science content standards, as well as teaching standards. The idea was that if administrators were more knowledgeable about the standards they would be better able to support teachers as they learned to use and implement national standards and reformed science teaching as part of their participation in the MSP program. Survey responses indicate that administrators came to the program with a lack of knowledge of inquiry-based science teaching and science content and teaching standards. Significantly, while administrators differed in their responses based on their role (e.g., principal, superintendent, or science supervisor), all administrators reported an overall uncertainty in their knowledge and school principals reported having the least knowledge. Data collected after completing ASI found all administrators, regardless of their administrative role, reported they were better informed about the national science content/teaching standards, research in science education, inquiry-based strategies and knowledge of distributed leadership.

A second goal of ASI was to expand administrators' knowledge about the inquiry teaching practices teachers enrolled in the MSP were learning how to implement in their own classrooms. Administrators participated in a series of reformed science lessons that sought to highlight how students learn science in authentic scientific investigations related to national science standards. During these lessons, administrators participated as students (see Figure 11). This was an important experience for administrators because many of them did not learn science through inquiry methods themselves. This experience allowed them to participate in an inquiry-lesson in order to better understand how this type of teaching can lead to higher-level thinking and deeper understanding.

(A) (B)

Figure 11. Administrators participate in the color changing milk activity. Photo A depicts administrators exploring the phenomenon and Photo B depicts their reflection on the activity in order to construct a scientific explanation of the observed phenomenon.

This experience allowed administrators to better understand the experience of the student in an inquiry-based classroom, the importance of the materials, and the role of the teacher. One urban principal said:

> Participation in this Academy has improved my ability to distinguish between inquiry-based instruction and learning in a traditional science classroom. Becoming familiar with teacher roles and student roles in the inquiry-based

> classroom, I can better evaluate and support my science teachers as they incorporate inquiry-based practices into their instruction (journal entry, 2009).

By participating in inquiry lessons, administrators were able to develop an improved understanding of inquiry teaching that would enable them to recognize and assess this type of teaching in their schools. After participating in the activity as students, administrators were then supported to step back from the activity and reflect on the experience from the perspective of a pedagogical leader. Administrators were introduced to the Reformed Teaching Observation Protocol (RTOP), which was designed to measures a teacher's use of inquiry-based (reformed) teaching practices, and they were asked to evaluate the lesson using the five subscales on the RTOP: *Lesson Design & Implementation*, *Propositional Knowledge*, *Procedural Knowledge*, *Communicative Interactions*, and *Student Teacher Interactions* (Sawada, et al., 2002). The RTOP was introduced to help focus the administrators' evaluation on inquiry and content specific aspects of the lesson. This exercise was important for building the knowledge and capacity of administrators to support changes in pedagogy aligned to reforms in science teaching. In an ASI evaluation, one administrator stated:

> You've given me insight and a knowledge base as to what she [teacher participant] is learning and should be doing in her own classroom so that now we have a common language (ASI evaluation, 2008).

An increase in knowledge of inquiry-based science appeared as a theme across data sources, including evaluations, video transcripts, surveys and journal entries. This data source triangulation strengthens this finding. By better understanding how students learn science in an inquiry classroom, administrators were able to develop the pedagogic leadership and leadership content knowledge necessary to support their teachers. This is important because administrators in the program saw how in their current evaluation system, teachers might be rated low and students might appear not to be learning things in an inquiry-oriented classroom. Overall, participation in the ASI provided administrators with new knowledge about how teachers teach reformed science in the K-12 classroom allowing them to more accurately interpret what they saw in their teachers' classrooms.

The ASI promoted measurable change in actions related to new knowledge. In this section I elaborate on action, which was the other category of growth based on the analysis of survey data. This category includes the actions administrators take in facilitating, supporting, and evaluating teachers in their practice based on an improved knowledge of teaching and learning science. This is significant because if administrators are to be instructional leaders in their schools, they must be able to provide teachers with information, as well as to recognize and support efforts to implement inquiry and action research to improve teaching (Robinson, Lloyd, & Rowe, 2008). Using my coding scheme, five categories of improved action emerged in the analysis of qualitative data: *curriculum and instruction*, *materials support*, *classroom culture*, *teacher feedback and evaluation* and *issues of distributed leadership*. These categories are important because they directly corresponded to the challenges science teachers face as identified by administrators through their work in the ASI with experts in the field and their partner science teachers. In addition, improvement in these areas is aligned with growth in reformed science leadership, specifically in how administrators use knowledge of science teaching and learning to lead teacher learning and recognize, observe and assess effective science teaching. In the section that follows, I use the voices of administrators and teachers to build robust explanations of these improved actions within each of the categories, summarized in Table 11.

Table 11.

Growth in Administrator Actions Aligned to Reformed Science Leadership

Category	Finding
Curriculum and Instruction	Administrators improved in their ability to support teachers to restructure curriculum for deeper understanding
Materials Support	Administrators recognized the need to support teachers through budgets and procedures to improve access to materials for scientific investigations
Classroom Culture	Administrators were committed to supporting teachers in issues of classroom culture and management seen as barriers to reformed science teaching
Teacher Feedback and Evaluation	Administrators recognized the disconnect between formal evaluations and reformed science teaching and focused on developing feedback mechanisms in line with teacher growth for science education reform
Distributed Leadership	Administrators recognized the need to engage and empower science teacher leaders

Curriculum and instruction. To develop proficiency as a reformed science leader, administrators will need to understand how curriculum is connected to national and state standards and authentic science problems. Through their participation in the ASI, administrators developed a baseline understanding of the role of the standards in the learning of science and became aware of their role in supporting teachers to refine curriculum in line with the goals of science education reform. During presentations in a fall session of the ASI, administrators recognized the tension between covering a breadth of material versus promoting the deeper learning stressed by the national standards. Reflecting on his time as a teacher, a principal emphasized he was:

> under the gun to cover the curriculum [and how this] goes against the idea of going deeper into certain content questions and doing investigations to answer student questions (video transcript, 2009).

Yet, the work in the ASI provided administrators with the knowledge and skills necessary to support teachers as they restructure the curriculum and corresponding instructional strategies based on the inquiry-based teaching the MSP aimed to support. Administrators began to recognize their role in providing instructional guidance to teachers in this process. As one administrator stated:

> I have to be committed to examining the curriculum with teachers to combine topics, and reduce redundancies existing at various grade levels (journal entry, 2007).

When principals facilitate professional learning communities, visit classrooms, and talk to teachers, they come in contact with curriculum and instruction, judge adequacy, and decide what help a teacher may need. If schools are to consistently provide high quality science instruction aligned to national, state and local standards, it is critical that administrators recognize and support the development of standards-aligned curriculum and reform-based instructional methods.

Materials support. During an ASI session, administrators spoke to the school structures that hinder the ability of their teachers to obtain materials to use in science classrooms. One principal highlights this barrier stating during an ASI session that, “you can’t take a purchase order to the grocery store.” Although this is documented as a challenge for their teachers, participation in the ASI supported administrators to recognize the need to support teachers by allocating funds in the budget, creating transparent policies and procedures for obtaining materials, and being open to requests from their science teachers for equipment and materials to support reformed teaching practices. In the words of a suburban district science coordinator, “It is my job to help my teachers that are using inquiry teaching to get the things they need to make it happen for their students in the classroom.” Teachers in the MSP program reported that after participating in the ASI their administrators were more approachable and more likely to authorize the purchase of materials. This increased support was likely based on their improved understanding of reformed science teaching gained through participation in the ASI.

Classroom culture. Administrators pointed to the challenges teachers face as they seek to relinquish control of their classroom in order to provide students with the freedom to explore science phenomena and build their own conceptual understanding through inquiry-based teaching methods. In addition, administrators highlighted the importance of a strong school culture, with high academic and behavioral expectations for students, to support reforms at the classroom level. Through participation in the ASI administrators committed to taking responsibility for developing a school culture that would encourage their teachers to take risks and restructure their classroom learning environment based on research on how students learn science. In his journal, one administrator voiced a sentiment shared among many of the administrators who participated in the ASI about the importance of supporting science teachers as they refined their management strategies to support reformed science teaching: “The management issues that arise from using inquiry-based teaching methods are my responsibility.” Statements such as this denoted an enhanced accountability for supporting teachers in areas of classroom management and culture pertinent to the goals of reformed science teaching.

Teacher feedback and evaluation. Teachers in the MSP reported a fear of implementing new pedagogical practices because it was not in line with what their administrators looked for during formal observations. The ASI gave administrators the opportunity to observe inquiry-based lessons and apply traditional and reformed observation protocols, such as RTOP (Sawada et al., 2002). Through this process administrators recognized the conflict between their formal evaluation process and an approach whereby they facilitate learning and teacher growth in line with reformed science leadership practice. One principal highlighted this realization in a presentation to her colleagues during an ASI session where she committed “to provide feedback outside of the formal observations so you really are a resource to those teachers" (video transcript, 2009). The ASI further supported administrators' ability to actually provide meaningful feedback by promoting an understanding of reformed science teaching as defined by the MSP.

Meeting the goals of science education reform will require reform-based science teaching that is student-centered, inquiry-oriented and includes multiple opportunities for collaboration among students. Principals are charged with creating a culture in the school around continued learning and professional inquiry. A principal's feedback informs a teacher's ability to implement reform-based teaching practices. Principals need knowledge of scientific content as well as how science is taught for optimal learning in order to effectively lead the planning, implementation, monitoring and evaluation of a strong curricular program in science that leads to high levels of student learning. As one urban, public school principal put it, "As the administrator monitoring instruction, it's important that I support teachers in implementing this strategy through professional development and collegial exchange" (journal entry, 2008). Participation in the ASI provided the foundation for changing administrator actions around teacher evaluation and feedback.

Distributed leadership. One goal of the ASI was to inform leaders about distributed leadership practice through subject matter (Burch & Spillane, 2003) in order to encourage them to practice this style of leadership in their districts and schools. Through participation in the ASI principals began to change their approach to leadership, especially as it related to the science teacher participants in the MSP program. Principals moved away from merely recognizing formal leadership roles in their buildings to promoting science teacher leadership, especially by empowering those science teacher leaders enrolled in the MSP program. One suburban district science supervisor emphasized this point stating:

> Participation in the [ASI] has heightened my awareness that leaders are found within a system regardless of hierarchy consideration, and are leaders by virtue of their actions to impart understanding of learning to others who may influence students. It is important to utilize leadership where it is found and to enable others to function as leaders by encouraging them, valuing them and removing constraints that might hamper their ability to function as a leader (journal entry, 2009).

While the quote above focuses on the actions of a district level administrator, building level principals also gained a new awareness of the content-specific leadership needed to support science education reform and demonstrated improved action in distributing leadership:

> I need the leadership among the teachers who are using the programs and strategies with the children to present what is working or what is not working. (journal entry, 2007).
>
> I agree that this academy has encouraged me to continue to include all voices from our school staff as decisions are made about academic and social aspects of our educational program…I have also allowed individual teachers and staff to fully organize and implement certain programs or lesson units that they came to me with as initial ideas to try (journal entry, 2008)

Participation in the ASI allowed administrators to enact credible knowledge of teaching and learning in order to empower science teacher leaders to exercise professional responsibility for applying a laser-like focus on student learning through the lens of how students best learn science. Pedagogical leadership and therefore reformed science leadership is predicated on distributed leadership practice (MacNeill et al., 2005). The ASI promoted changes in leadership practice that were content and context specific. The ASI sought to bring together issues of content and leadership and build the understanding that school sites have the expertise and leadership through their teachers to work through changes (Burch & Spillane, 2003). The focus on the interaction of multiple leaders (district administrators, principals, department heads, and science teachers) in service of reformed science teaching offers considerable leverage for school wide pedagogical change in how science is taught and learned.

Contradictions to demonstrated growth in reformed science leadership practice. Even with the positive actions, there were still contradictions. Specifically, one principal from an urban district described her hesitancy to truly distribute leadership in ways that empowered her teachers. The principals wrote:

> Last year, my school was selected to participate in a District/University Distributed Leadership pilot program. We introduced the program to our staff and they voted against implementing the program in our school….I also learned from talking to program officials, that the principal's role and decision-making power were significantly reduced under this model of leadership. The school principal is ultimately responsible for every circumstance arising out of decisions and actions made by its staff so I would

> be uncomfortable relinquishing so much of that control to others (journal entry, 2007).

This sentiment demonstrates that even when administrators were well-informed about and encouraged to create a distributed leadership model at the school, principal's sense of accountability for everything that happens to children in a school (Markow, Macia, & Lee, 2013), inhibited them from taking actions to support this practice.

Summary of Impact of the ASI on Administrators

Participation in the ASI promoted growth in knowledge and actions of school administrators related to key understandings of science teaching and learning and reformed science leadership practice. Administrators developed an understanding of inquiry teaching and learning in science classrooms and strategies for building professional learning communities and a school learning culture. This knowledge led to improved actions by administrators related to how they approach science curriculum and instruction, science teacher evaluation, materials acquisition, shared leadership and student discipline. Administrators emphasized these points as a key focus of school improvement plans and a frequent part of their discussions and reflections. However, despite these areas of growth, administrators faced persistent challenges as they sought to support inquiry-based teaching and learning through reformed science leadership practice.

Administrators Face Challenges as They Seek to Support Science Teachers

In this section I discuss three challenges (1) Superficial knowledge of science teaching and learning (2) Low self-efficacy to support professional growth of science teachers and (3) Working in isolation to achieve reform that emerged as administrators attempted to grow as leaders for science education reform. I then offer an interpretation about why ASI was not sufficient for addressing these persistent problems of practice. To improve validity of my findings, the emergent challenges were triangulated through analysis of survey data, journal entries and video transcipts of ASI sessions.

Superficial knowledge of science teaching and learning. Despite the learning that took place in the ASI, analysis of qualitative data revealed inconsistencies in how administrators thought about science teaching and learning indicating a persisting lack of knowledge of the content and pedagogies associated with reformed science teaching. Administrators recognized the ASI as an opportunity to merely begin to think about tenets of reformed science teaching. One principal from a large urban district admitted, “I did not think very much about inquiry-based instruction. I had heard about it and thought I really knew about it until I started reading the articles that were handed out in class” (journal entry, 2007). Another principal from the same urban district demonstrated a superficial understanding of science education reform when she wrote:

> New science standards require greater academic proficiency from students. They require students read texts of immensely greater complexity and ask thoughtful questions that will guide inquiry and problem solving. But are all students prepared for this type of learning? …. *How can a teacher involve students in problem solving and hands-on learning with 33 or more students in his or her classroom? It is a real challenge in many schools* (journal entry, 2007).

By questioning whether all students can engage in the type of learning promoted by science education reform, due to academic readiness or large classrooms, this principal demonstrates that she does not truly understand reformed science teaching. In fact, reformed science teaching is grounded in the belief that *all* students deserve the right to develop a deep understanding of science as a way of knowing and can do this by engaging in multiple modes of inquiry, where students make sense of the world, ask questions, and solve new problems. Reformed science teaching suggests that we build on where students are coming from, focus on moving away from teacher talk toward student argumentation around evidence, and enable students to drive their own learning through reflection. Neither academic readiness nor class size precludes a science teacher from reaching these goals.

Although administrators may have some basic knowledge of science education reform, they lack a deep understanding of the science content and pedagogy that underlies it. This point is salient, as scholars have argued that subject matter is an important context for teachers’ work (e.g., Shulman, 1987; Stodolsky & Grossman, 1995) and, therefore, one might expect that an administrator’s subject matter expertise is critical for science reform leadership. An administrator’s credibility and depth of understanding of science pedagogy and associated learning and teaching processes will influence their proclivity to engage in discussions with classroom teachers on matters pertaining to classroom practices (Silcox & MacNeil, 2006). This expectation is supported in the literature because as principals become more knowledgeable in the content and more aware of the ways in which students best learn science, a significant advantage emerges (Stein & Nelson, 2003). One specific study (Nelson, Stimpson & Jordan, 2007) focused on the teaching and learning of mathematics found that administrators were not well-equipped for some of the leadership functions they reportedly performed—setting a vision for the district's mathematics program, selecting mathematics curricula, communicating with parents and stakeholders, recruiting and hiring math teachers, conducting classroom observations and supervising teachers. While all of these functions are critical to a successful mathematics program, many of the school and district leaders who reported having the most substantial responsibility for these functions had weak mathematics knowledge, were uncomfortable with mathematics, and had relatively traditional views about mathematics instruction or, at best, a superficial knowledge of contemporary ideas about mathematics instruction. This finding can speak to science teaching and learning because there is specific knowledge of scientific content, science and engineering practices, and crosscutting concepts that must be considered in order to plan and supervise effective instruction. Therefore, the limited knowledge administrators have of key research, policy and practice that support science education reform poses a real challenge for science education reform as it likely limits these leaders in developing a vision for science education and supporting reformed science teaching in their schools.

One administrator in an urban, public school said, "As an assistant principal I have a little knowledge about everything" (journal entry, 2006). This is consistent with the literature, which suggests that principals are unlikely to have specialized content and pedagogical knowledge about multiple content areas or at all grade levels (e.g., Nelson & Sassi, 2000; Spillane, 2005). Although the ASI provided a variety of learning experiences intended to inform administrators about science teaching and learning, administrators still did not leave the short program with expertise needed to transform science teaching and learning in their schools. Most professional development programs for principals are not context specific and provide little content-specific training. For example, there are some programs that have been shown to improve the effectiveness of already effective principals (Clark, Martorell, & Rockoff, 2009), although most district professional development for principals receives low marks (Seashore-Louis et al., 2010). This particular program was rated highly by participants, but was still limited in its ability to develop the extensive content and pedagogical knowledge necessary for reformed science leadership.

Low self-efficacy to facilitate teacher learning through PLCs and effective feedback systems. Administrators reported a variety of obstacles preventing them from fully supporting their teachers' efforts to improve science instruction at the school level, including lack of physical resources, top-down protocols for teacher observation and evaluation, limited funding, and pressure to ensure student success on standardized exams measuring achievement in math and reading, but not science. This challenge was persistent despite participation in the ASI as indicated by a lack of growth in the subsections of *support* and *culture*. Aligned with my theory of reformed science leadership, administrators lacked the efficacy to support the science teaching profession based on their limited knowledge about how teachers learn and teach science, which made it difficult for them to build a professional learning culture around science pedagogy and content. I suggest that in order for school reform to be sustainable, it is essential that administrators find ways to support professional growth of science teachers and evaluate the effectiveness of the approach by gauging how these strategies are integrated into the culture of the classroom and school community based on knowledge of effective science teaching. A lack of self-efficacy emerged as a major constraint that prevented administrators from promoting professional learning focused on coherent, science-specific instructional guidance. Self-efficacy is the "set of beliefs a person has about their capabilities and more importantly the judgments they make about them to execute particular courses of action and do specific things within their belief parameters" (Bandura, 1977, p. 3).

Analysis of administrator beliefs shows that administrators generally believed in the importance of supporting their teachers in reformed science teaching. For example, one urban administrator said "the classroom teacher needs on-going training in inquiry-based instructional techniques so they can identify concepts best suited for inquiry and plan appropriately for investigations" (journal entry, 2007). However, analysis of the data suggests that administrators did not believe in their capacity to provide this on-going training and support necessary for refining these reformed science teaching practices, due to their lack of leadership content knowledge for building professional learning communities based on teaching and learning science. In addition, administrators indicated the difficulty they had evaluating effectiveness of science pedagogy based on knowledge of effective science teaching.

Analysis of video of ASI sessions and administrator journal entries further illuminated the challenge resulting from the low self-efficacy of administrators to facilitate science teacher learning through effective feedback. One science coordinator described this as he reflected in a journal entry on a learning activity in the ASI where administrators were asked to participate in a lesson representative of reformed science teaching:

> After lunch we observed a demonstration lesson. We were grouped as students or administrators/observers. The teacher led an inquiry-based lesson using a variety of instructional methods. The observers sat and, using their particular observation system, evaluated the lesson. There were many layers of instruction to ultimately understand why crops are sprayed with water during potential frost/freeze conditions. Inquiry-based instruction can be difficult for teachers to utilize if they are so familiar with teacher-directed instruction. We as administrators may have to visit the class for several days to actually determine if all students learned. The discussion afterwards examined the lesson and we discussed how difficult it is to observe a lesson like this. Because of the layered instruction, it is very tough. Some of the observers found it useful to mingle amongst the students and ask them questions about their learning… We also had a high school lesson demonstrated for us using inquiry methodology. This type of teaching will take some getting used to for any staff that engage in it, and it will be difficult for me to evaluate it as well (journal entry, 2006)

This reflection demonstrates the challenge faced by administrators as they seek to evaluate a science lesson and subsequently provide supports for professional learning to promote pedagogical changes and refine inquiry teaching to meet the goals of reformed science education. Research suggests that more effective school leaders have a high efficacy orientation (DeMoulin, 1991). Since administrators are unlikely to have had teaching experiences that provide them adequate content knowledge for leading pedagogical changes in science, they have lower self-efficacy in this area, and therefore find it challenging to appropriately practice reformed science leadership and facilitate teacher learning.

Furthermore, principals recognized their role, but lack agency to influence pedagogical change. One suburban, district-level administrator noted those qualities she aims to support but described the difficulty she faces in actualizing these efforts:

> As a supervisor, I must allow experimentation (educational) within the classroom. I need to recognize conceptual knowledge in more than one standard form. I must engage teachers to encourage students to transfer conceptual knowledge and to present a spiraled approach to the curriculum. I must afford students the opportunity to learn by doing and learn by error. This is a challenge, indeed. (Journal entry, 2006)

Low self-efficacy poses a challenge because even when administrators have strong knowledge of science education reform, they still operate in a reactive rather than proactive manner. Less efficacious leaders are less likely to attempt to apply skills to school related tasks associated with pedagogical change (Silcox & MacNeil, 2006). In group discussions during the ASI, administrators demonstrated their low self-efficacy when they lamented that even when they wanted to do things, they were limited by bureaucracy, limited funds, lack of support, limited time, and fear of losing control or failing with new ways. This attribution detracted from the development of self-efficacy necessary to practice reformed science leadership.

Working in isolation to achieve science education reform. Administrators reported that they feel extremely isolated in their daily work. Survey data revealed that administrators have limited interactions with administrators outside their schools and districts and very often do not interact with administrators who work in environments different from their own (e.g., suburban rather than urban, private rather than public). Analysis of survey data revealed the smallest gain in the area of *collaboration* after participating in the ASI. Administrators strongly agreed or agreed with statements in the survey that suggested they had limited opportunity to collaborate, such as, “I have limited interactions with administrators outside of my school.”

In ASI discussions, surveys and journal responses, administrators reported that the experience in ASI provided them with improved access to an administrator network that they lacked in their own schools and districts. For example, in evaluations of the ASI administrators reported their appreciation for the “strong network of ‘science-minded’ mentors” and “the time to collaborate and reflect with peers from other districts.” In addition, one principal from a small, private, suburban school discussed the value in interacting with administrators from a large, urban, public school district, stating:

> whenever I meet administrators from [large city], I am always impressed with all that they have to offer. I really enjoyed speaking with them and listening to all the innovative ideas they have implemented in their schools (journal entry, 2006)

Many administrators expressed hope that such networks could diminish their sense of isolation, but they lacked the time to take advantage of opportunities to collaborate. Thus, the networks they developed during the ASI were not sustainable over time. This point was further emphasized by post-survey results that show even after participation in the ASI over the course of an academic year, administrators still reported feelings of isolation and a lack of interaction with administrators from other schools and districts. Analysis actually revealed an *increase* in feelings of isolation after participating in the ASI, perhaps because administrators became aware that this was one of the few opportunities they had to collaborate with other administrators. This challenge is important because reformed science leadership is collaborative in nature and requires deep understanding of science content and pedagogy. When administrators lack access to professional learning communities (PLCs), they do not have the opportunity to support one another to professionally grow in the areas necessary for reformed science leadership. True PLCs are collaborative activities with a focus on working together to improve student achievement by responding to data on student learning (Eaker, DuFour, & DuFour, 2002). In the case of administrators, a professional learning community would focus on teacher learning and implementation of the practices in line with reformed science teaching and learning.

The research on administrator isolation is sparse, especially as it relates to administrator effectiveness or professional growth and development. Literature suggests that isolation is a variable that works in concert with stress and contributes to the overall quality of the work experience, such as burnout (Stephenson & Bauer, 2010). Consistent with my findings, the principal's role carries with it a degree of isolation (e.g., Dussault & Barnett, 1996). Dussault and Thibodeau (1997) found that this isolation could negatively impact a principals' performance at work. Therefore, the isolation of administrators can be a considerable challenge as they seek to implement new practices aimed at supporting reformed science teaching.

Furthermore, we can extend our knowledge from studies on content-specific collaborative learning of teachers for student success (i.e., through PLCs) to infer that if administrators did engage in collaborative relationships it would greatly contribute to their own professional growth, improve teacher learning and ultimately increase achievement of the students in their schools (Eaker, DuFour, & DuFour, 2002). The PLC model gives schools a framework to build teacher capacity and has the potential to build administrator capacity to work as members of high-performing, collaborative teams that focus on improving student learning through reformed science leadership.

A Contradiction to These Challenges

These findings highlight specific challenges that emerged as administrators participated in the ASI. I chose to highlight these challenges related to my framework of reformed science leadership to provide an overview of the barriers to this type of leadership practice that persist despite participation in a professional development program. Focusing on these persistent challenges allows us to recognize the limitations of a short-term professional development program for teachers and administrators. In the section that follows I highlight a contradiction that emerged through one particular structure of the ASI: collaborative administrator-teacher action research projects.

Value of collaborative projects. During participation in the ASI, administrators and their science teachers were encouraged to participate in a collaborative action-research project. Through this work, administrators and teachers worked together to implement a particular change and evaluate the effectiveness of this change using data Four projects emerged as a testament to the power of this approach for meeting the challenges of reforming science education by employing collaborative ethnographic research within their individual schools. Table 12 summarizes the context and aim of each of these projects. The projects were completed by administrators in partnership with their science teachers enrolled in the MSP program.

Table 12.

Sample Collaborative Administrator and Teacher Projects

Project Title	Project Context	Project Aim	Project Method
Science Education Done Collaboratively	Urban public school serving approximately 400 students grades K-8; 98% African American, 75% free and reduced lunch	To integrate science instruction with language arts, math, social studies and technology.	Design a school roster that enables science teacher to better support the regular classroom teachers as they implement science core curriculum
Get Out of the Cart and Push!	Urban Catholic school serving approximately 850 students grades pre-K-8	To develop a science program throughout the school that is deep rather than broad and that is hands-on and mind-on at every level	Redefining and recognizing excellent teaching behavior, supporting development of teamwork based on scheduling of common planning time, increasing use of the school science lab
Teacher Support and Success of Students with Disabilities	Urban charter school serving grades 9-12; 17% of student body identified as having a disability	To increase success of students with disabilities in science	Collaboration between science teacher and the Director of Special Education
Science Education: Functional Science	Urban public school serving approximately 230 students grades 6-8	To provide students various experiences in science and make science an integral part of daily school life	Forging partnerships with community-based organizations to broaden students' experiences in science and extend science education beyond the walls of the traditional classroom

Analysis of artifacts from these collaborative research projects revealed that this type of collaboration served to significantly reduce the challenges listed above. Through this work, administrators worked with teacher participants to become experts in a particular area of related to science education reform, thereby developing their leadership content knowledge (LCK). This experience provided the opportunity to develop expertise together and witness the impact of actions thereby improving self-efficacy of administrators for supporting other science teachers in a similar manner. Finally, these collaborative projects served to build partnerships between administrators and teachers in ways that reduced isolation. The photographs in Figure 12 represent evidence collected by administrators and science teachers as part of the action research completed to document the impact of the project.

Figure 12. Photo artifacts from collaborative projects.

Studies suggest that professional development that attempts to change the culture of the school has a greater potential for systemic reform than does professional development geared solely at the individual teacher (Khourey-Bowers, Dinko, & Hart, 2005). Some research has shown that teachers can implement and sustain positive change in schools where administrators and teachers have formed a community dedicated to the teaching and learning of their students (Silva, Gimbert, & Nolan, 2000). These collaborative projects represent a strategy that helped classroom teachers introduce and sustain new teaching practices learned in the MSP program with the support of their administrator. They also provided an authentic learning experience for administrators to build their leadership content knowledge in ways that improved their efficacy in supporting pedagogical changes in science.

Limitations to the Study

This study explores the influence of a professional development program on administrators and the challenges administrators faced as it relates to implementation of reformed science teaching. However, there are limitations to the approach. This study is limited to data collected from a small number of participants. The study examines a sample of administrators of teacher participants in an MSP program, which limits the study participants to a particular type of administrator—one who would agree to support a science teacher as they participated in a program focused on inquiry-based teaching situated within a prestigious university. A second limitation is in the data available. Although survey data was used to describe growth due to participation in the ASI, only a small number of administrators actually completed both the pre- and post-surveys. Another limitation to the data was that administrators were limited by prompts for surveys, journal entries, and discussions in the ASI. Therefore, administrators answered the survey questions and interview questions that were asked and may not have had the opportunity to provide additional information that may have led to a different set of challenges and opportunities.

Conclusions

The NGSS require that science concepts build coherently across K-12, focus on promoting deeper understanding and application of content, and aim to prepare students for college, careers, and citizenship. Thus, the NGSS reflect a new vision for American science education because they focus on conceptual understanding, problem-solving, application of science in real-world contexts, and the ability to draw evidence-based conclusions. Reform-based teaching aims to be consistent with the nature of scientific inquiry, reflects scientific values, requires the use of data to justify positions and takes its time to ensure students learn deeply. The literature suggests that administrators' leadership content knowledge (LCK), or knowledge of the subject matter of the instruction and how it is best taught and learned, is critical to their effectiveness as school and district leaders (Stein & Nelson, 2003) and their ability to support teachers (Spillane, Halverson, & Diamond, 2004) in implementing this new vision. Furthermore, administrators are essential in providing content specific, pedagogic leadership to science teachers by empowering teachers to exercise professional responsibility and enacting credible knowledge of teaching and learning (MacNeill et al., 2005). This research focuses our attention on the need for administrative leadership in the area of science teaching and learning.

I confirm through this work that many administrators are not fully informed about the current research on how students learn science. In addition, administrators are not especially well informed about the research-based evidence supporting the use of inquiry-methods for teaching science at the K-12 levels. Evidence suggests that administrators must have a degree of understanding of how a subject is learned and taught and it is inadequate for them to merely generalize this information from one subject to another (Stein & Nelson, 2003) if they are to promote and sustain reform-based changes in teaching and learning of science. My findings demonstrate the influence of a professional development program focused on reformed science teaching on administrators of science teachers enrolled in an MSP program. I found that even a limited professional development opportunity in the form of the ASI can result in positive changes in administrator knowledge and practice. As administrators become more knowledgeable in content, policies, and practices related to science education reform, they also demonstrated improved actions specifically related to this new knowledge. For example, when survey data revealed improved knowledge of national science content and teaching standards, it also showed an increase in consultation of these standards documents. Similarly, as administrators became more knowledgeable about inquiry-based teaching they were more likely to encourage science teachers to use inquiry in their practice.

Administrator actions improved in ways that supported components of reformed science leadership. Indeed, administrators were more likely to recognize the role they serve in facilitating changes to the instructional guidance systems and access to materials necessary for supporting a change to inquiry-based teaching. These improved actions are salient because administrators need to be familiar with the nature of curricula and instructional materials that are available and the implications of this for the nature and design of professional learning opportunities for teachers (Prestine & Nelson, 2005). Administrators in this study began to help teachers with alignment and spiraling of curriculum and instruction in order to make room for inquiry. Furthermore, administrators and teachers alike recognized the improved understanding of the need for appropriate materials to engage students in authentic science learning experiences. This improvement directly addresses the obstacle of inadequate science equipment for hands-on, inquiry-based teaching that has existed since the 1970s (Tilgner, 1990). As a result of participation in the ASI administrators supported teachers to get supplies by approving requests or creating procedures that made getting materials easier. The ASI focused on the intersection between administrator leadership and teaching and learning of science, which succeeded in changing two specific actions that serve to promote inquiry teaching and learning in science teachers' classrooms.

Administrators also developed improved actions in areas related to their school culture—from professional learning to classroom management support to shared leadership. Rather than solely focusing on their formal evaluation systems, administrators were exposed to new protocols, such as RTOP, for guiding observation and feedback that were standards based, inquiry oriented, and student centered (Sawada et al., 2002). Administrators expressed a renewed commitment to promoting science teacher professional learning by applying their knowledge of science content and pedagogy in ways that supported teacher growth and development. In addition, administrators and principals noted the need to acknowledge and provide support related to classroom management as teachers began to restructure their learning environment in order to shift to a student-centered approach. Lastly, a group of administrators also became more committed to the practice of distributed leadership as they became aware of their limited knowledge of science teaching and learning and the growing expertise of the science teacher in the MSP program. As administrators learned about the benefits of distributed leadership, they became more committed to creating a culture that makes room for teachers to meaningfully participate in important conversations about teaching and learning, with all stakeholders, in a professional setting (Silva, Gimbert, & Nolan, 2000). This culture can be one of distributed leadership, coparticipation, mutual respect, and shared responsibility. However, the focus on sharing leadership was not unanimous. In fact, some administrators were reluctant to share leadership with science teacher leaders because they were aware that they, as formal leaders, were ultimately responsible for the outcomes.

With a shifting role of the principal from manager to instructional leader, principal professional development programs, such as the ASI, are needed to provide administrators with the knowledge they need to be effective leaders (Elmore, 2007; Levine, 2005). Considering that effective leadership plays a pivotal role in how a subject is taught, ensuring appropriate preparation and in-service support, including foundational knowledge of subject-specific pedagogy and content, is extremely important. The ASI provided foundational knowledge necessary for administrators to better support their science teachers to implement reformed science teaching practices promoted by the MSP program. However, while the ASI provided specific development resulting in some changes in administrator knowledge and actions, the ASI was less effective at changing actions that directly bumped up against the challenges described in the findings. The ASI did not result in an increase in the support of the science teaching profession based on leadership content knowledge in ways that built a professional learning culture based on teaching and learning science. In addition, the ASI was not successful in reducing feelings of isolation. These areas are in line with the persistent challenges identified in this research, such as the acquisition of superficial knowledge of science content and pedagogy and low self-efficacy for supporting science teachers. Additionally, administrators faced continued isolation despite the fact that the ASI created an opportunity for administrators to network with one another and with teachers, except in the case of collaborative projects between administrators and science teachers. This isolation was persistent because of the lack of time administrators had to take advantage of this expanded network due to the increasing stress of the job. In addition, administrators were unlikely to collaborate with other administrators or teachers because they saw the accountability for student success increasingly falling on their shoulders.

The challenges that emerged as a part of this study make evident the need to focus on professional learning for administrators, including finding ways to build an administrator's community of learners. The administrators in this study continued to report feelings of isolation throughout their time in the ASI. Post-survey data suggests that participation in the ASI actually *increased* feelings of isolation. It seems that as administrators began to see the value of collaborating with individuals with similar roles, their awareness of how little they actually interacted with other stakeholders as a learning community emerged. From a community of practice perspective, a learning community emerges when "people who share a concern, a set of problems, or a passion about a topic deepen their knowledge and expertise in this area by interacting on an ongoing basis" (Wenger et al., 2002, p. 4). Even though administrators interact with stakeholders on a daily basis, they are not engaged in a community of practice centered on reflection on learning and the ways in which their own ideas and practices contribute to the way that science is taught and learned in their buildings. Additionally, administrators did not tend to collaborate with teachers in ways that built their own knowledge about reformed science teaching practices and in turn enhanced their self-efficacy for supporting this work by their science teachers. Administrator and teacher professional development must consider these opportunities and challenges as they devise programs to improve implementation of science education reform.

Implications

The findings in this study have implications for science education reform. This study suggests that there is a need to consider the influence of administrators when designing professional development programs for in-service science teachers. My findings support the idea that science education reform can only be realized when we think about the learning of leaders in ways that promotes and supports reformed science teaching and learning. Not only did I find that administrators tend to come with little knowledge of science subject matter or science-specific pedagogies, I found that even a limited professional development program can improve the working knowledge of administrators in this area. However, despite the improvements I highlight there were still areas of improvement that remained stagnant and challenges that lingered.

Given the persistent challenges facing even these administrators participating in the ASI, a new model for science teacher and administrator professional development is needed. In addition, it is important to consider the interface between leadership and teaching and learning if there is to be change in classrooms, schools, districts and the system as a whole. While research suggests that administrators must have sufficient content knowledge in most subjects to effectively lead pedagogical change (Stein & Nelson, 2003), it is clear that limited professional development may provide administrators with content knowledge that is necessary, but not sufficient. This is where a focus on science teacher leadership becomes increasingly important. A subset of the leadership literature focused on instructional improvement is premised on the idea that most of the knowledge required to improve teaching and learning in schools resides in the people who deliver instruction, rather than those who manage them (Elmore, 2000; York-Barr & Duke, 2004). This underscores the importance of empowering teachers to become experts in their content, innovative in their pedagogy and confident in their abilities as leaders, to support administrators in the work of reforming instruction in ways that lead to improved student understanding.

These implications can inform those who design programs for teachers aimed at improving the implementation of science education reform. I recommend that programs for science teachers develop a complementary program for administrators in order to focus on the interface between leadership and teaching and learning in ways that are consistent with the tenets of science education reform. An effective professional development program would focus attention on developing leadership content knowledge and pedagogic leadership. The ASI provided an entry point for administrators to begin to develop their reformed science leadership and those administrators who participated in the ASI benefited greatly from participation in the program. However, this program did not sufficiently address all of their challenges. Another iteration of this program would keep some aspects of the design intact, enhance others, and include additional components.

Research supports the idea that administrator leadership is influenced by personal and contextual variables (e.g., Hallinger, Bickman, & Davis, 1996). Therefore, it is necessary for professional development programs to consider the demographics of the administrators and science teachers, as well as their school environment, when creating programs for administrators and teachers focused on improving science. Science education reform is predicated on the belief that all students deserve the right to develop a deep understanding of science in the context of daily life as well as to develop agency to drive improvements in the local and global community through the application of science and technology. To continue to be aware of issues of inclusion and identity that amplify the voices and strengths of each student and local community members in the classroom, a professional development program must acknowledge the context of the administrators and the different challenges that their teachers and students face. Therefore, developing a coherent model for reformed science leadership development would include attention to general approaches, with room for adjusting the program to include context-specific components.

A new approach to professional development would build on lessons learned from the ASI and require a reorganization of the knowledge bases to assist administrators in developing credible knowledge of science content and inquiry-based teaching, as well as better preparing administrators to recognize and support reformed science teaching and empower science teacher leaders. This model for administrator development in reformed science leadership comprises instruction, models, and assisted practice in areas that promote general knowledge and skills as well as in context-specific learning. The model would focus on the following general areas:

1. Learning more about the specific program the science teacher is participating in

2. Developing an understanding of inquiry teaching and learning in science classrooms
3. Building a culture for professional learning and shared leadership
4. Creating a professional learning community of administrators

Administrator professional development programs should occur concurrently with science teacher professional development, target building-level leaders, and build sustained social networks for easing feelings of isolation and creating communities of practice. When administrators work together they can and do create policies that improve science teacher quality (Shen, Gerard, & Bowyer, 2009). Administrator participants recognized the structures of the ASI that promoted shared learning as some of the most valuable. Furthermore, administrators appreciated the opportunity for them to network with other administrators, become aware of what they are doing, how successful they are and how they solve problems and encourage success. Administrator comments support that more time was needed to truly learn deeply about science pedagogy and content and to build the team, suggesting that a longer, more sustained development program would be preferable for truly creating deep learning and a community of practice.

In addition to the general learning activities mentioned above, the program should provide opportunities for context-specific work. The ASI brought administrators and teacher participants together and this practice was deemed one of the more valuable components of the program. Therefore, a future model would allow science teachers and administrators to work together even more closely in a sustained and focused manner. For example, administrators and science teachers might take on collaborative action research projects in order to consider problems of practice that are context-specific. In this way, they would see modeled in their own learning activities the same approaches and pedagogical techniques they would be expected to use with their students. The methods used would involve co-construction of meaning by bringing together administrators and teachers so they can work together as members of communities of practice. These projects would be enacted through materials, teachers, learners and administrators, as a product that is provides context-specific learning based on the environment in which it is enacted.

The overall design of professional development should not be seen as the singular approach to improving reformed science leadership, but as a starting place for developing the knowledge and skills necessary to develop in this practice. In this model, administrators are able to learn from experts in the field, borrow ideas from each other, and participate in collaborative research projects to test out new ideas in their unique school environment, all in service of improving the implementation of reformed science teaching. If we are to realize the goals of science education reform, we must consider how we educate administrators to support this vision through their work with science teachers and other stakeholders.

CHAPTER 5 – "THAT WILL OPEN SOME EYES:" UNDERSTANDING HOW ROLES AND DEFINITIONS OF SCIENCE TEACHER LEADER IMPACT K-12 SCIENCE EDUCATION REFORM

Introduction

Leadership is essential for creating the vision for a school and inducing all stakeholders to work together in order to promote changes in instruction and improve student learning (Bryk et al. 2010, Neumerski, 2013; Spillane & Diamond, 2007). Over three decades ago, Edmonds's (1979) landmark study provided empirical evidence that effective schools almost always have leaders focused on instruction. Building principals initially served as these instructional leaders. As education becomes more specialized, especially at the secondary level, teachers are needed to provide expertise in their grade-level and subject-area (Spillane & Halverson, 1998; Stein & Nelson, 2003). Research suggests that teacher leaders have the greatest likelihood to change school-wide instruction (Danielson, 2006; Mangin & Stoelinga, 2008; Marks & Printy, 2003; York-Barr & Duke, 2004). Focusing on teacher leaders who teach and lead well can provide evidence about how teacher leaders facilitate changes in practice that lead to increased student success.

In light of the current emphasis on enhancing scientific literacy and raising graduation in the sciences (NAS, 2005; NAS, 2012), a focus on science teacher leadership is a potentially powerful strategy to promote effective, collaborative teaching practices to increase student achievement in science. Few studies attend to how teacher leaders in general define and perform their roles, how other teachers respond to their work, or how they facilitate instructional improvement (Mangin & Stoelinga, 2008; Neumerski, 2013; Spillane & Diamond, 2007). Even fewer studies focus on teacher leadership in the sciences as a strategy for facilitating reforms in science education (Rebello, Hanuscin, & Sinha, 2011). This study seeks to better understand how science teachers engage in leadership practice by documenting how science teachers define and characterize the roles they play in schools and the practices they enact. Building from these findings, I discuss how school context and participation in content-specific professional development can contribute to roles and definitions of science teacher leadership.

Background

In this section, I provide a review of the literature on instructional leadership, especially as it relates to science teacher leaders. Then, I make the argument that science education in the United States is in need of improvement and discuss Math-Science Partnership program, a professional development program for science leaders, which is the context of this study. By focusing on science teacher leadership, this paper will provide implications for realizing reformed science education in service of student success.

Science teacher leadership for improved student understanding. Teacher leadership, in general, emerged in schools and districts over the past few decades as a means of addressing the isolated nature of teaching and the desire to increase teacher status (York-Barr & Duke, 2004). The concept of teacher leadership came to fruition in schools with school accountability (the process of evaluating school performance on the basis of student performance measures) as teacher leadership was seen as a way to improve teaching (Smylie, Conley, & Marks, 2002). Encouraging teacher leadership can provide a means for supporting pedagogical change that is subject-specific, promoting collaborative professional learning, and improving teacher status.

Although there is little consensus around what constitutes "teacher leadership," it tends to encompass a range of activities: teacher leaders promote changes in instruction, take on administrative duties, or hold a formal leadership role (Neumerski, 2013). Teacher leaders can be consultants, curriculum managers, department chairs, mentor teachers, professional development coordinators, resource teachers, specialists, coaches, and demonstration teachers (Mangin & Stoelinga, 2008). In literature and policy, teacher leaders are often out of the classroom full-time, although some teacher leaders assume leadership tasks in addition to full-time teaching or less often, combine part-time teaching and part-time leadership (York-Barr & Duke, 2004). A subset of the literature on teacher leadership focused on instructional improvement suggests that under appropriate conditions teacher leaders can contribute to improvements in teaching (Smylie, Conley, & Marks, 2002; York-Barr & Duke, 2004). However, other research on teacher leadership and instructional improvement suggests that teacher leaders provide insufficient instructional support with little influence on the instruction of their colleagues (Mangin, 2006). This suggests that more needs to be known about the conditions for teacher leadership that lead to improved teaching. One particular condition, that has received little attention, is the understanding of the subjects that teacher leaders and their colleagues teach (Manno & Firestone, 2008; Riordan, 2003). Learning more about the role of content specific leadership roles is another important component of understanding teacher leadership for instructional improvement and is the focus of this paper.

The literature suggests that leadership content knowledge (LCK), or knowledge of the subject matter of the instruction and how it is best taught and learned, is critical to the effectiveness of a leader (Stein & Nelson, 2003). Therefore, to understand how teacher leadership can influence science education reform it is necessary to look specifically at science leadership practice. According to the National Science Teachers Association (NSTA), science leaders play a crucial role in the areas of science teaching and learning, professional development, science curriculum, and assessment (NSTA, 2003). Science leaders must focus on the essential elements of science education reform, such as aligning curriculum, instruction, and assessment with national, state and local standards; implementing professional development based on district and state needs and ensuring that the infrastructure needed to sustain the science program over time is firmly in place (NSTA, 2003). Science teacher leaders must be present at the school level but also must work with administrators in order to realize systemic reform. Science teacher leaders can hold formal and informal roles (York-Barr & Duke, 2004) and there are multiple pathways that propel science teachers into these leadership roles. For example, some science teachers have pursued leadership development through professional development programs or formal training programs. Other science teachers have developed their leadership knowledge through mentoring relationships or collaborations with others through professional societies. Finally, other science teacher leaders have been identified as leaders by their building administrators and encouraged to assume leadership roles. The section that follows makes an argument for the importance of science education reform and speaks to the role professional development programs for science teacher leaders can play in supporting the development of science teacher leaders.

Science teacher leader programs as a lever for improving science education. If the goal of reform science education is improved understanding of science content by students and authentic application of scientific and engineering practices, then instructional practice must change to align the teaching and learning with this goal. Reformed science education refers to this change in the approach to science teaching and learning. Although funding agencies and foundations have dedicated significant funds to reforming science education in the past, progress towards these goals continues to be slow. As we move into a new era of reform for science education, we must focus on the role that science teacher leaders play in facilitating reforms in science education.

One program that seeks to reform math and science by building capacity and integrating the role of higher education with that of K-12 is the Math and Science Partnership (MSP) program at the National Science Foundation (NSF). The MSP program, launched by the NSF in 2002, funds research and development efforts that support innovative partnerships to improve K-12 student achievement in math and science. The MSP program focuses on reducing achievement gaps in the math and science performance of diverse student populations. Partnerships between institutions of higher education and K-12 districts are created to effect deep, lasting improvement. MSP programs have 5 key features, (1) partnership-driven; (2) teacher quality, quantity and diversity' (3) challenging courses and curricula; (4) evidence-based design and outcomes; and (5) institutional change and sustainability. One specific program of the MSP is focused on meeting national needs for teacher leaders/master teachers who have a deep knowledge of disciplinary content for teaching and are fully prepared to be school- or district-based intellectual leaders in math or science. Since teacher leadership is a powerful lever for promoting reform, these programs provide an important context for studying science teacher leadership.

The purpose of this study is to explore how science teacher leaders engaged in two MSP programs engage in and define leadership practice. This study provides the foundation for looking more deeply at how science teacher leadership might improve student learning and has implications for the ways in which policy and practice around teacher leadership evolve.

Research Design

Theoretical Framework

Approaches to leadership in the literature include a range of leadership concepts, such as participative leadership, instructional leadership, pedagogic leadership, leadership as organizing, distributive leadership, parallel leadership, and transformational leadership (Leithwood & Duke, 1999; MacNeill et al., 2005; Ogawa & Bossert, 1995; Spillane & Diamond, 2007). In this study, I use the concept of leadership practice (York-Barr and Duke, 2004) to profile the roles of science teacher leaders. In the following section, I describe the seven dimensions of leadership practice, both formal and informal, based on empirical examples from the literature (see Table 13).

Table 13.

Dimensions of Leadership Practice

Dimension of Practice	**Example Teacher Leadership Activities**
Coordination, management	Coordinating events, administrative meetings and tasks, monitoring
School or district curriculum work	Defining standards, selecting and developing curriculum
Professional development of colleagues	Mentoring other teachers, leading workshops, peer coaching, modeling/encouraging professional growth
Participation in school change/improvement	Taking part in school-wide decisions, facilitating PLCs, participating in research, challenging status quo
Parent and community involvement	Encouraging parent involvement, creating partnerships with community, working with community and community organizations
Contributions to the profession	Participating in professional organizations, becoming politically involved
Pre-service teacher education	Building partnerships with colleges and universities to prepare future teachers

Note: The information in this table was summarized from York-Barr and Duke, 2004

These leadership roles include instructional, professional development, and organizational functions, which I use to characterize the roles science teachers report as leadership practice. In the section that follows I introduce the concept of transformational science leadership as a lens for analyzing teachers' definitions of science leadership practice.

Transformational science leadership. To look at definitions of science teacher leadership I use the frameworks of transformational leadership and leadership content knowledge (LCK) to construct a framework for transformational science teacher leadership. Transformational leadership encompasses many of the other approaches to teacher leadership and focuses on the commitments and capacities of organizational members for continuous improvement (Leithwood & Duke, 1999). Transformational leadership is leadership through collective action that empowers those that participate in the process (Leithwood, Jantzi, & Steinbach, 1999). Transformational leadership facilitates a redefinition of mission and vision and a renewal of commitment by all stakeholders, as well as a restructuring of systems to meet goals. Leadership content knowledge (LCK), similar to the idea of pedagogical content knowledge (Shulman, 1987), is the knowledge of the subject, how it is learned (by adults as well as students) and how it is taught that is used by instructional leaders (Stein & Nelson, 2003). Transformational leadership and LCK are typically used in education to describe the building principal but I extend these frameworks by using them to analyze science teacher leadership practice. Transformational science teacher leadership is collaborative, focused on authentic learning experiences for students connected to national, state and local standards, promotes inquiry-based teaching and empowers stakeholders (administrators, other teachers, students) to participate in pedagogic change.

Methodology

In this mixed methods study, I used a quantitative approach to provide a profile of science teacher leaders engaged in the MSP programs. This deductive analysis set the foundation for the qualitative analysis that followed. The qualitative analysis sought to answer questions about *how* teachers define leadership and *what* factors influence their leadership practice. Figure 13 summarizes the mixed methods approach used to answer the research questions in this study. This schematic demonstrates how the quantitative analysis informed the qualitative analysis that followed.

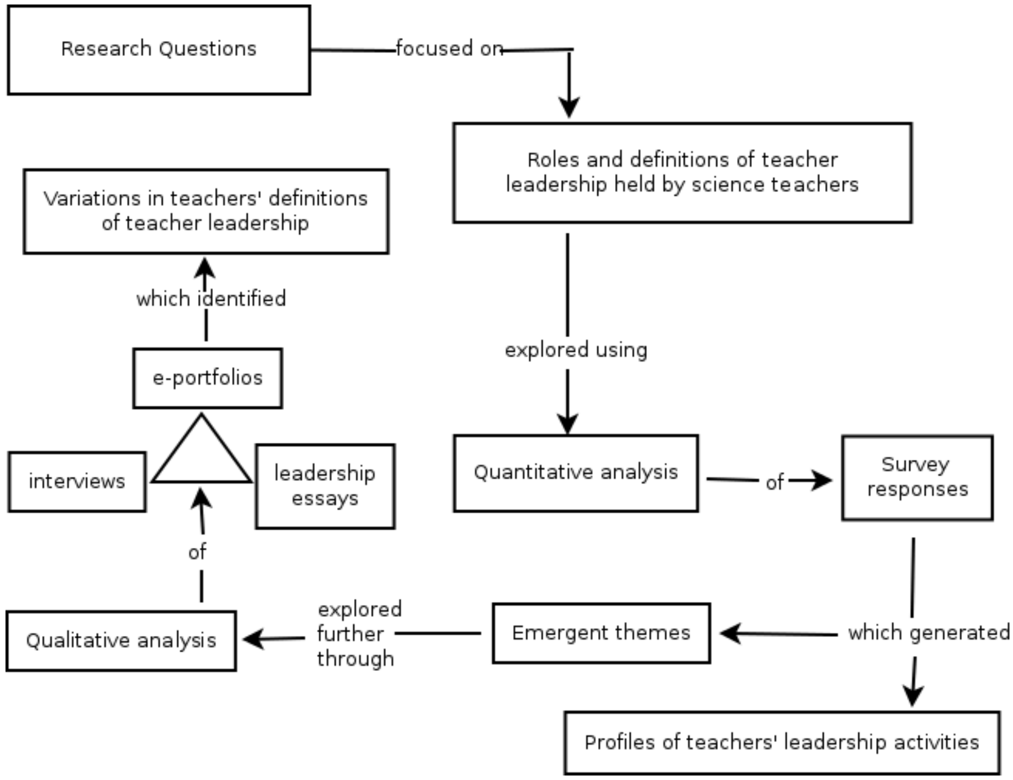

Figure 13. Schematic diagram of mixed-methods approach for connecting data.

Deductive analysis was used in order to categorize teachers' open-ended responses to the MSP leadership survey based on the seven dimensions of leadership practice (DLP) (York-Barr & Duke, 2004). After categorizing teachers' responses, graphs were created to represent frequency of responses in each dimension of leadership practice. This enabled me to create an overall picture of the types of leadership activities in which science teacher leaders enrolled in the MSP program participated. I used inductive means to look for emergent themes related to the roles science teachers played and the ways they defined leadership in survey data, leadership essays and e-portfolios using the framework of transformational science teacher leadership to extend the analysis.

Research Questions

The research questions relate to the ways in which science teachers engaged in a MSP program, intended to develop teachers as leaders, view leadership practice. The questions are as follows:

1. What leadership roles do science teachers play in their classrooms, schools, districts and nationally?
2. How do teachers define leadership in science education?

Context

This study explores the research questions within a longitudinal professional development program for teachers and administrators in two MSP programs. MSP 1 was a collaborative initiative between an urban northeastern university's chemistry department and school of education, focused on providing in-service teachers with content knowledge, science education theory and model instructional strategies in order to encourage teachers to implement reform-based teaching practices in their classrooms. Another outcome expected by program administrators was that the graduates would become teacher leaders in their schools and/or districts. In the context of the program, science teacher leadership refers to teacher-participants working collaboratively with their colleagues to share their new pedagogical and content knowledge gained from participation in the MSP 1 program (Blasie & Kahle, 2009).

In this study, I focus on five years of the program, when teacher leadership became a more integral focus of MSP 1. Approximately half of the participants serve student populations from Title 1 schools, or those schools impacted by Title 1 of the US Department of Education Elementary and Secondary Act which receive funding based on having a high percentage of students from low-income families. Furthermore, participants represent diverse school settings including public, private, parochial, and charter schools from five northeastern states. The professional development program consists of 10 courses, eight on chemistry content knowledge and two focused on the theory and practice of teaching and learning chemistry

MSP 2 is a collaboration among a private, Midwestern university, field trip sites, and the city public schools. This unique collaboration worked together to establish the advanced degree program and leadership training for teams of high school biology teachers. MSP 2 was designed to enhance content knowledge and pedagogy, through a blend of life science research and content and science education research and methods. It consists of two, three-week summer institutes at the university focused on disciplinary content and online coursework during the academic year focused on pedagogical strategies for incorporating new content into teachers' classrooms. The program also aims to develop science teacher leaders. To this end, the program instituted a leadership program, which continues to engage teachers upon graduation.

Over a 5 year period, MSP 2 has enrolled approximately 110 teacher participants, representing urban, suburban, and rural school districts from all over the United States. Criteria for selection included certified teachers with at least three years teaching experience, some leadership experience and/or leadership potential. The stated goals of the program were to develop a national cadre of master teachers who demonstrate intellectual engagement with, and mastery of, global issues in life science, and who use related research-based pedagogy and challenging content in their courses. The program also sought to promote partners' and participants' development as local and national educational leaders.

Data Collection and Analysis

Consistent with mixed methods methodology, multiple sources of evidence were collected and used in this chapter (see Figure 14).

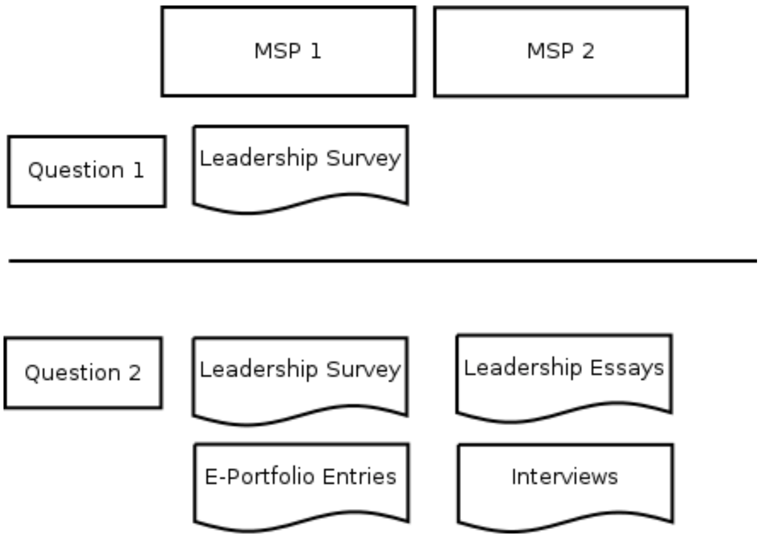

Figure 14. Data sources used to answer each research question.

The data collected were selected in order to maintain a chain of evidence for the findings (Yin, 1994). A mixture of deductive and inductive reasoning was used to develop a coding scheme (Miles & Huberman, 1994). In addition, multiple sources of data were used to investigate each research question as a means for triangulating the data.

The survey was used as a larger pool of data, which included all participants from MSP 1. Analysis of survey data provided a large data set to examine trends in self-reported leadership practice along the seven dimensions as outlined by York-Barr and Duke (2004). In addition to these dimensions, codes included the *role of science pedagogical content knowledge* and *definitions of teacher leadership*. For research question 1, the answers on the surveys of all cohorts were used. I then pulled a subset of representative teachers from MSP 1 and MSP 2 and examined their e-portfolios, leadership essays and/or interviews and did parallel tabulations as in the survey data to triangulate the data and highlight any contradictions. I then analyzed the e-portfolios of teachers from MSP 1, leadership essays from MSP 1 and 2 and interview transcripts from MSP 2 to expand on definitions of science teacher leader and the influence of school context and the MSP. I used the framework of transformational science leadership to guide my analysis. Convergence of the data was used as a method for corroborating findings and divergence of the data allowed for surfacing contradictions (Marshall & Rossman, 1999).

Surveys. During their participation in the MSP 1, teachers reported their leadership activities on online leadership surveys during Years 1 and 2 of the program and graduates completed an exit survey. The survey included categories of leadership: facilitating, presenting, coaching/mentoring and consulting, based on the project directors' appraisal of these activities as "high impact" transformational leadership practice. The leadership survey, developed by project leadership for internal program evaluation, included ten questions that asked teachers to select which of the above leadership practices in which they participated. Additionally, two questions were open-ended, which asked teachers to describe their leadership activities (Kahle, Li, & Scentlebury, 2010). This research focused on three survey questions in order to characterize the roles that teachers play in their schools and districts and describe the ways they define leadership practice based on the seven dimensions of leadership practice (York-Barr & Duke, 2004) and the additional codes: science pedagogical content knowledge, definitions of teacher leaders, role of administrator and influence of the MSP.

Electronic portfolio (e-portfolio). The e-portfolio was a high stakes assessment that was added as a degree requirement to MSP 1 in 2005. Teacher participants were required to use the e-portfolio to demonstrate their growth as a result of having participated in the program. It was required that participants use appropriate baseline and corresponding post-baseline evidence to explain and depict growth within all e-portfolio rubric item entries (e.g., what the evidence was, why it was chosen, and how it illustrates growth). Thirty-six e-portfolio entries with supporting evidence were analyzed to provide evidence for teachers' definitions and perceptions of leadership practice using the framework of transformational science leadership.

Leadership application essays. Both MSP1 and MSP2 required teachers to apply to the program and asked teachers for information about their ideas about leadership, including examples of how they have exhibited leadership. In MSP 1, teachers used excerpts from their application essays in their electronic portfolios to demonstrate how their definitions of leadership and involvement in leadership activities had changed. In MSP 2, teachers were asked to select a leadership theory they most identified with and write an essay about why they selected this leadership theory and how they experienced this leadership in the daily life of teaching. These leadership essays were analyzed using inductive means in order to characterize teachers' definitions of leadership. In order to describe teachers' definitions of science leadership, the framework of transformational science leadership was applied.

Findings

Using the lens of leadership practice and transformational science teacher leadership, I found that science teachers participate in and privilege some science leadership roles over others. In addition, I found that many science teachers define leadership differently than current policy and practice. The MSP programs as well as the teaching context influenced both roles and definitions of science teacher leader, which has implications for preparing and supporting science teacher leaders. The section that follows summarizes these findings using multiple data sources in order to triangulate the findings for increased validity and clarity. I provide key quotes and exemplars to further describe the themes as well as acknowledge the contradictions that emerged to these patterns of coherence.

Claim 1: Teachers Participate in and Privilege Certain Domains of Leadership

All teachers reported science leadership activities on the survey, despite the small number of teachers occupying formal leadership positions, such as science department chair (n = 21) or district leadership positions (n = 1). This suggests that science teachers legitimize other leadership activities that are not necessarily connected to a formal, leadership position. The open-ended survey allowed teachers to report on any science leadership activities that they participated in. Analysis of survey responses based on the seven dimensions of leadership practice revealed that teachers reported activities that fell mostly in three areas: coordination and management, working on curriculum for their schools or districts, and participating in professional development of colleagues, by hosting workshops or mentoring other teachers. This suggests that these activities are the most common for science teachers to participate in.

Self-reported coordination and management activities include organizing science laboratories, facilitating science fairs, and leading after school clubs. For example, one teacher described her involvement coordinating an after school club, stating:

> I am the moderator of an environmental science club called the Green Thumbs. I have the club meet every other week and we focus on ways to raise environmental awareness. There are approximately 30 students in the club and this year we participated in campus clean ups, tree planting, invasive species removal … I started this club last year and find it to be very rewarding. I organize all the activities for the club and looking for more ways to get the students and other members of the school community involved. (MSP 1 teacher, leadership survey, 2010).

This quote highlights the ways that this teacher coordinates student activity in the club as a specific type of science leadership activity. Teacher leadership activity reported in the area of curriculum included designing courses, aligning standards and assessments, and modifying labs. Finally teachers reported participating in professional development of colleagues through sharing pedagogical and instructional activities during department meetings, arranging professional development workshops, and discussing teaching practices with colleagues (Figure 15).

Figure 15. Self-initiated science leadership activities reported by teachers in MSP 1, 2008-2010. The frequency represents absolute number of responses not number of participants.

One teacher described her leadership activity, stating:

> My only roles to date have been in providing professional development with a group of other teachers on a web-based lesson plan program (requested by my principal) to my school and individually providing professional development and follow-up training and support to my grade level colleagues in creating and using webquests in the classroom (asked by my colleagues). (MSP 1 teacher, leadership survey, 2009)

This quote exemplifies the type of professional development activity most frequently reported by teachers as science leadership activity. It also adds to the claim that teachers privilege specific forms of science leadership. In this case, the teacher adds that she was asked by her principal and colleagues to provide professional development, which shows how recognition from others adds to the legitimacy of the activity. Leadership roles, especially coordination and management of events and meetings, tend to dominate the field of teacher leadership (Jackson, Burrus, Bassett, & Roberts, 2010). This could be because teachers look to their administrators for guidance regarding in which leadership activities they can and should participate. One teacher expressed this feeling by writing, “there is nothing to volunteer for, everything is delegated by administration.” This representative quote provides evidence that administrative structures impact the roles and perceptions of leadership practice. The lack of collaborative science teacher leadership reported by science teachers as suggested by their administrators or colleagues (Figure 4) indicates that administrators need a better understanding of transformational science teacher leadership practice in order to empower teachers to lead from their classrooms.

Of all the dimensions of leadership practice, involvement of pre-service teacher education was the activity least frequently mentioned. This suggests that either science teachers in the MSP programs are not engaged in this work or that they do not see this as an important leadership role. In addition, many teachers cited writing grants to receive materials to support inquiry-based science. This activity was not easily categorized into one of the seven dimensions and likely emerged more frequently within this study population due to the role materials play in reform science teaching. One teacher stated:

> I also have written 2 grants this year which were fully funded to help receive materials for the plant growth and development unit. (MSP 1 teacher, leadership survey, 2008)

This specific leadership activity was frequently mentioned by teachers in their surveys, e-portfolios and other data sources and speaks to the importance of understanding science content and pedagogy when considering leadership roles for teachers.

The qualitative analysis revealed more about how teachers privileged leadership roles that were recognized and validated by their colleagues and administrators. I found that a sample of teachers openly indicated skepticism about their roles as science leaders even when these teachers indicated their involvement in more informal, collaborative leadership activities. For example, one teacher reported that she had no leadership activities to share, then subsequently gave an example of something that could be classified as participation in school change:

> I am teaching first grade this year and have not had any leadership activities...I have however been teaching science and sharing ideas with my grade partner. (MSP 1 teacher, leadership survey, 2008)

From this statement I can infer that by sharing ideas about teaching and learning of science with her grade-level partner she was using her knowledge of science pedagogy and content to facilitate professional learning. This is a component of leadership based on transformational science leadership practice even though the teacher did not perceive herself as a leader. Results from the survey also indicated that when teachers engaged in collaborative work that focused on instructional improvement, they did not see this as leadership practice. Although these teachers worked together in informal professional learning communities to implement science teaching and learning improvements, they did not see this as leadership. One teacher stated:

> I have not had any science leadership activities during this year, however I worked with my grade partner to co-plan implementation of the science core curriculum in our classroom. (MSP 1 teacher, leadership survey, 2009)

This builds on findings by Hanuscin, Rebello, and Sinha (2011) that while science teachers are engaged in a wide range of activities, they do not consider many of these activities leadership. Most teachers were able to provide an example of some activity that they considered science leadership but the majority of these activities fell in categories focused on managing a specific project or team or leading a group. These activities are those that typically receive external validation, in terms of recognition or pay, for the work. One teacher reflected this sentiment during an interview about her experience in MSP 2,

> You know, saying [I am a] NOYCE Master Teacher Fellow, that will open some eyes in my district. Saying editor/publisher of case studies will open some eyes. You know I think those pieces are really important to have that external validation. (MSP 2 teacher, interview, 2011)

Science teacher leaders perceive leadership activity as that which receives recognition though this often cannot be earned when engaged in more informal, collaborative leadership efforts.

Claim 2: Science Teachers Offer a Different Definition of Leadership than Current Research and Policy

What precedes this section examines teachers' leadership experiences and provides a profile of teacher leadership activities. In the sections that follow, I examine definitions of teacher leadership and teachers' views of themselves as leaders. During initial analysis of the data it became evident that teachers were thinking about leadership in two distinct ways. The ways that teachers perceive leadership is important for better understanding appropriate policies and practices for empowering teacher leaders. Teachers involved in the two MSP programs tended to describe teacher leadership as legitimate science leadership or transformational science leadership. Legitimate teacher leadership describes teachers who refer to leadership as holding a formal leadership position or doing an activity to or for others, rather than in partnership with others. This definition comes with external validation in terms of title, recognition, or money. This notion of leadership is similar to traditional instructional leadership practice. The second definition of leadership is aligned with notions of transformational science leadership that is done collaboratively to improve student learning of science and contribute to science education reform. Generally, teachers who speak about leadership practice as working with others to enact instructional improvements and reforms in science education would fall in this category.

When teachers were asked to report their science leadership activities, a larger percentage (59% on the survey and 75% in the e-portfolio) of teachers reported participation in legitimate science leadership activities. Interestingly, when teachers were asked to explain how they defined leadership, without reference to their own leadership practice, a slightly larger percentage of teachers actually defined teacher leadership as a collaborative endeavor in service of student achievement (56%).

Legitimate science leadership. Teachers who highlighted legitimate science leadership practice reported leading professional development workshops, chairing the science department, managing inventory, serving on committees and mentoring others by sharing expertise. These teachers highlighted activities that fit with a definition of leadership shared by an MSP 2 teacher in her leadership essay: "Successful leaders know how to instruct subordinates and effectively delegate tasks" (MSP 2 teacher, leadership essay, 2007). This same teacher explained that holding a specific leadership role leads to a necessary "external validation" that teachers seek. Teachers who adhered to a definition of legitimate science leadership practice focused on specific roles they were able to fill and what they were able to give to others as science leadership practice.

Although much of the literature on teacher leadership emphasizes the ability of all teachers, regardless of position, to contribute to school improvement, science teachers in this study reflect a resurgent interest in formalization of teacher leadership roles. In the 1980s and early 1990s, leadership roles for teachers were a common reform strategy (Mangin & Stoelinga, 2008). More recently, federal initiatives have created a resurgence of new leadership positions in districts and schools. Teachers in this study reflect this focus on a more traditional definition of leadership, based on a particular role.

Transformational science leadership. The second variation of science teacher leadership is more closely aligned with the framework of transformational science teacher leadership. Transformational science leadership is leadership that is focused on reformed science teaching and pedagogic change in order to improve student learning of science. Transformational leadership is achieved through collective action that empowers those who participate in the process (Roberts, 1985). In this study, transformational science leadership practice was used to identify teacher leadership activity that was collaborative, focused on reforming science education, and ultimately aimed to improve the authentic learning of science by students. In this study, one teacher defined this variant of teacher leadership by saying:

> The ability to lead in science education is predicated upon the ability to work cooperatively at many levels. Personally, I am beginning to define leadership as a set of relationships that foster respect and a common desire to help improve the understanding of the subject matter of the various sciences nationally and globally (MSP 2, leadership essay, 2007)

Though many science teachers in the MSP programs did not define leadership in this way or provide examples of leadership practice that would be classified as transformational, this teacher was able to take the traditional definition of transformational leadership and apply it to science teacher leadership.

The perspective of transformational science leadership underscores teachers' potential to lead science education reform efforts despite a lack of positional leadership authority. One teacher defined this type of leadership in her portfolio: "Teacher as leaders is a teacher who collaborates with other science teachers in a professional manner and has some type of influence on others" (MSP 1 teacher, e-portfolio, 2008) One common leadership activity described by teachers who identified leadership practice as collaborative and informal was co-teaching. Teachers described their efforts to co-plan and co-teach as an activity, which required them to take on a leadership role:

> In this coming school year, I will be co-teaching with another science teacher. We will be meeting this summer to discuss how the material is to be covered and what our responsibilities will be. (MSP1 teacher, leadership survey, 2008)

Co-teaching is model of teaching that emphasizes situated learning within a construct of collective responsibility, reflection, and mutual respect (Scantlebury, Gallo-Fox, & Wassell, 2007). Teachers whose definitions of science teacher leadership not only focused on involvement of many stakeholders, but specifically focused on the importance of the subject matter expertise for improving the teaching and learning of science.

Evidence in the research literature suggests that transformational leadership makes a difference in educational settings and that positive outcomes of this form of leadership are mediated by factors such as teacher commitment, instructional practice, or school culture (Hallinger & Heck, 1998; Leithwood, 1994). Extending transformational leadership from the leadership of the building principal to teacher leadership can develop capacity and commitment of teachers and students, increase teacher agency and ultimately lead to improved student outcomes. Further, adding a content-specific focus to transformational leadership has the potential to further refine policy and practices that retain excellent science teacher leaders, improve instruction, and lead to increased student success in science.

Conclusions

I set out with this research to answer two questions: (1) What leadership roles do science teachers play in their classrooms, schools, districts and nationally? And (2) How do science teachers define leadership in science education? In this section I summarize and extend the specific findings for each of the research questions, provide patterns and inconsistencies in the findings and offer interpretations of the results.

Leadership Roles for Science Teachers

This study suggests that many teachers are doing what they consider science leadership, but that these activities are more likely to fall in three categories: 1) coordination and management; 2) school or district curriculum work; or 3) professional development of colleagues. Fewer teachers reported their science leadership activity as working with pre-service teacher education, parent and community development, participating in school improvement or other contributions to the profession. In addition, when teachers reported their leadership practice, the smallest contribution was in areas of school improvement. This could be because they do not participate in these activities or that they do not view them as leadership. In answering the second research question, I found teachers' definitions of leadership tended to align more with activities that require coordination, management or control and receive external validation. Therefore, it may be that science teachers are participating in more informal leadership activities, but they are not reporting them here. This is consistent with Hanuscin, Rebello, and Sinha's (2011) findings that suggest that teachers do not see certain activities as leadership, especially those that are categorized as contributions to the profession (e.g., becoming politically involved and participating in professional organizations).

There is a disconnect between research and practice of science teacher leaders. Current research emphasizes the inextricable connection between teacher leadership and teacher learning, job-embedded work connected to instruction (e.g., Hart, 1994). However, teachers tend to see leadership as external to their daily work and as additional responsibility. The science leadership activities that teachers report on tend to encompass positions and roles external to their day-to-day work, such as managing a specific program or project or providing professional development opportunities to colleagues. Many teachers are either doing what they consider leadership activities that fall in three categories or at least tend to identify those categories as leadership. It is interesting to note that the things seen as teacher leadership are managerial and role-based in nature, rather than collaborative.

Science Teachers Define Science Leadership in Different Ways

The findings in this study draw attention to the lack of clarity in defining science teacher leadership. Even when teachers are engaged in a program dedicated to developing transformational science teacher leaders they provide different definitions of science teacher leadership. Teachers in the MSP programs most often associated being a leader with holding an externally validated role, such as serving in an official capacity for an organization or taking charge of an event (such as a professional development workshop) while others listen and follow. Practices related to their day-to-day work of science teaching were not recognized as leadership. Most teachers tended to define leadership by management and control. For example, many teachers stated that they have grown as a leader because they had led a specific professional development session, presented at a conference, or been promoted to science department chair. The other definition of science leadership was more in line with conceptions of transformational science leadership, focused on collaboration with others to improve science teaching practice and student achievement. This definition was promoted by the MSP, but not the most common definition cited. Even when science teachers recognized these practices as leadership, they still sought external validation for their participation in order to legitimize these leadership roles. This poses a problem for the implementation of current policies and practices, which focus on teacher collaboration in an environment that encourages innovation.

Connections to Policy and Practice.

The Teacher Leader Model Standards (2011) describe knowledge and skills that may be useful in identifying teacher leaders and offer some considerations for practice, as well as strategies for implementing teacher leadership roles within schools and districts. The Teacher Leader Model Standards each focus on improving student learning and include seven domains that are aligned with the domains of leadership practice proposed by York-Barr and Duke (2004) and used in this paper as a framework for analysis.

These domains of teacher leadership stated in the Teacher Leader Model Standards are aligned with second definition of teacher leadership discussed above, where teacher leaders work as teachers but exercise transformational leadership with their colleagues in order to improve student learning in their schools. This variant was the least common way that teachers defined and reported leadership activity. Recognizing that this is the direction of policy, it is important to think about ways that policy directions can begin to align with teachers' definitions of leadership such that teachers are actually empowered to lead from their classrooms. This will require schools to recalibrate their leadership roles and the ways they define and legitimize science teacher leadership practice.

Limitations of the Study

This study explores the roles that science teacher leaders play in their schools, districts and nationally and the ways in which they define science teacher leadership and as such suffers from some of the limitations of exploratory research. This study is limited to a small study with selected participants. The study examines teacher participants in two different MSP programs, which limits the study participants to a particular type of science teacher—one who would apply and be admitted to a program at a prestigious university. These teachers are already likely the leaders in their own buildings and are further developed through their participation in the MSP program.

A second limitation is in the data available. Although survey data was used to create the initial profile of roles for science teacher leaders, only the teachers enrolled in MSP 1 took this survey. Data on leadership from MSP 2 came from leadership essays and was used to contextualize the anonymous survey data used for the initial overview of the roles that science teacher leaders play. Teachers in MSP 1 also had leadership essays, although the prompt they were given was not identical. Furthermore, reflective pieces from MSP 1 teachers were available that were not available for MSP 2 teachers. Interview data was collected only for a small cohort of MSP 2 teachers. Although the data collected from the two programs was different, the combination of the data sources collected through the MSP programs provided enough information to garner insight into the important issue of science teacher leadership.

Another limitation to the data was that teachers were limited by prompts for surveys, leadership essays, interviews and e-portfolio rubric. For example, the e-portfolio rubric provided examples of leadership activities that would be acceptable to use for a passing grade. Many teachers used the suggested activity in their e-portfolio reflection. Furthermore, teachers answered the survey questions and interview questions that were asked and may not have had the opportunity to provide additional information that may have led to a different view of them as science teacher leaders.

Implications

The literature suggests that teacher leadership has the greatest potential for changing school-wide instruction (Danielson, 2006; Mangin & Stoelinga, 2008; Marks & Printy, 2003; York-Barr & Duke, 2004). This study looks at science teacher leadership in particular in order to begin to define what types of activities teacher leaders are currently engaged in and analyze the ways in which teacher leaders personally define teacher leadership. Since we know that teachers have the greatest effect on student academic gains (e.g., Wright, Horn, & Sanders, 1997), keeping great teachers in the classroom and extending their influence as teacher leaders should be the highest priority for educational programs, such as MSP programs, and policy makers. This is especially important because of the demonstrated need for leadership content knowledge (LCK) for providing specific information about how a specialized subject, such as science, is best taught and learned (MacNeill et al., 2005; Stein & Nelson, 2003).

Keeping great teachers, who are making a difference in student achievement, will require different models of teaching and new roles for teacher leaders within current structures of schools. The teacher leaders in this study tended to define leadership as something external to their everyday job of facilitating student learning. This analysis raises important implications for practice and policy in developing teacher leaders. Even when teachers begin to see leadership as a more collaborative endeavor, they still tend to seek out formal roles. Science teacher leaders yearn for recognition that often cannot be earned when engaged in an informal, collaborative leadership effort. These data support the conclusion that programs and policies must put structures in place that recognize authentic, collaborative leadership efforts more formally to reward teachers for their important work in ways that encourage them to continue in that role. In addition, these structures must emphasize the importance of focusing on the learning that occurs and a commitment to improving student outcomes.

Teacher leadership programs need to address the range of how teachers see leadership and the experiences they have and think of a component to foster in teachers an awareness of what's possible, even if they do not see this in their current teaching position. In addition, teachers also need help imagining what is possible within their place at this time—or in the future. When programs build confidence of teachers in trying to develop teacher leaders, but then teachers do not see the opportunities in their positions, they may choose to leave the classroom to pursue leadership opportunities outside of classroom teaching. Therefore, these programs aimed at developing teacher leaders may actually be sending great teachers outside of the classroom. In this study, through surveys, e-portfolio reflections and interviews, teachers shared this newly acquired confidence. This same confidence makes it important that there are actually pathways for them to use their new knowledge and skills to collaborate with others in a way that is recognized. As we strive for educational reform, we must reimagine roles for teachers that empower them to lead from the classroom. Otherwise, we will continue to lose ground, as our best teachers move out of the classroom to move to the "top" in order to make a contribution to educational reform.

I conclude this paper with recommendations for program developers and policymakers that honor the important work of science teacher leaders in ways that encourage them to teach and to lead from within their schools.

Towards a Coherent Model of School-Based Teacher Leadership

In order to satisfy teacher leaders, new models will need to be created to educate teachers about what constitutes leadership, empower teachers to be leaders in their buildings, and recognize teachers so they do not just feel like a classroom teacher with a lot of extra work. In this study, teachers described a model of teacher leadership that was informal and collaborative, but still recognized by their colleagues and administrators. This calls for the creation of dual roles for teachers. In traditional schools, teachers are either full-time teachers, or they leave the classroom to write curriculum, coach other teachers, pursue a doctorate degree or lead a school as a building principal. This study supports the creation of what Berry and the TeacherSolutions 2030 Team (2011) refer to as a "teacherpreneur." A "teacherprenuer" role would allow teachers to remain active in their classrooms part time while also working outside of it, focusing on education policy, research, or community involvement (Berry & TeacherSolutions 2030 Team, 2011).

In order to do this, policymakers, programs, and individual schools must consider how they might create a dynamic and flexible learning environment for students and teachers that would allow for reimagined teaching positions that combine an element of impacting school change with teaching students. In addition, policies should be developed that might professionalize teaching such that it becomes a well-compensated career with many pathways. In addition, new roles need to be developed for classroom experts, who we do not want to leave the classroom to share their expertise, but rather provide them the opportunity to stay in the classroom with a reduced teaching load while simultaneously pursuing research, writing curriculum, occupying a role to influence educational policy, participating as a community organizer and serving as a trustee of the profession.

As we seek to create change within our education systems, a focus on teacher leadership will be an essential component. The current focus on teacher leadership has many stakeholders, including students, policy makers, K-12 building administrators, and teacher educators. What teacher leadership means for each of these groups is different. As teacher leadership moves to the forefront of policy and practice, it raises multiple questions. Does an individual have to be a great teacher to be a teacher leader? Can every teacher be a teacher leader? What knowledge and skills are necessary to acquire in order to be an effective teacher leader? Do teacher leaders need to have a specific background in order to be successful in working with their colleagues? How do we recognize teacher leaders in ways that keep them teaching in classrooms and schools? While these questions are being contemplated nationally and internationally, a starting point for analyzing these questions must first be to look at the practices teachers currently engage in how teachers define teacher leadership. This research seeks to provide foundational knowledge about how teachers view teacher leadership in order to inform policy and practice in ways that will support our teacher leaders to continue to teach and lead, and most importantly, contribute to the success of our students for years to come.

CHAPTER 6 – WHAT INFLUENCES SCIENCE TEACHERS' ABILITY TO LEAD WITHIN AND BEYOND THE CLASSROOM?

Introduction

A number of recent national reports have called upon K-12 educators to improve instruction in science, technology, engineering, and mathematics (STEM) in order to safeguard U.S. global leadership in these fields (NAS, 2010; NRC, 2002). In order to do this, schools will need to hire and retain excellent science teachers. Staffing the nation's classrooms with qualified mathematics and science teachers has been a key educational issue over the past two decades (e.g., Darling-Hammond, 1984). Research suggests that there is an adequate supply of math and science teachers, but points to the high attrition of these teachers from the profession (Ingersoll, Merrill, & May, 2012). It is increasingly difficult for schools to retain their best science teachers in order to meet the demands of teaching for deep understanding of scientific content and practices.

Research points to strategies that recognize science teachers as professionals as one option for keeping them in the profession (Tobias, 2010). Professional development programs for science teachers can develop the teaching and leadership skills through programs that emphasize content and pedagogy (Loucks-Horsley, et al., 1998). However, studies show that many teachers do not have adequate opportunities for advancement in their schools unless they leave the classroom. One study suggests that over one fifth of math and science teachers that leave teaching each year do so for non-teaching jobs within the education sector, such as school administration or curriculum development (Ingersoll & May, 2010). Depending on their school context, teachers are able to demonstrate leadership practice or feel compelled to leave. This study seeks to uncover the hindrances and affordances to science teacher leadership practice in order to better understand how to support science teacher leaders to lead from the classroom.

Literature Review

Science and Math Teacher Retention

Teacher attrition in the areas of math and science is an important area for research in science education. Findings have shown that the size of the teaching force combined with the relatively high annual turnover means that there are large flows in, through, and out of schools each year (Ingersoll, 2006). This issue is especially important in science and math teaching because unlike fields such as English, there is not a large cushion of new teachers relative to turnover, causing an overall staffing shortage (Ingersoll & May, 2010). In addition, over the past two decades, rates of mathematics and science teacher turnover have increased (Ingersoll & May, 2010). Current research on teacher attrition demonstrates that there are multiple reasons that teachers leave the profession. Studies (Borman & Dowling, 2008; Ingersoll, 2006; Ingersoll & May 2010; Ingersoll & Perda, 2010) examining attrition rates of science and math teachers indicate that a majority of those who leave teaching commonly report dissatisfaction due to lack of support from their administration, ineffective professional development, and lack of influence over school decision-making as the main cause. Other studies have demonstrated that science teachers who are unable to implement teaching practices outside of direct instruction are more likely to suffer from "teacher burn-out" and more likely to leave teaching than those supported to engage their students in learning experiences that involve inquiry and critical thinking (Butler-Kahle, et al., 2000).

Professional Development Programs for Science and Math Teachers

A few studies suggest that teacher preparation and professional development programs may be influential in stemming attrition of teachers, especially in K-12 school science (Ingersoll, Merrill, & May, 2012; Loucks-Horsley, et al., 1998). Research suggests that teachers' education and pedagogical preparation are significantly associated with their attrition (Ingersoll, et al., 2012). Teachers with more courses in teaching methods and strategies, learning theory or child psychology, or materials selection are significantly less likely to depart. Notably, math and science teachers are less likely to have had comprehensive pedagogical education, in terms of methods and theory courses, practice teaching, observing others, and receiving feedback on teaching (Ingersoll, et al., 2012). Since science teachers tend to enter teaching without adequate preparation in pedagogical methods and skills, in-service professional development is key for developing science teachers in ways that prepare them to excel as science teachers and lead among their peers. Participation in useful professional development is associated with a lower level of teacher turnover. In fact, when math and science teachers participate in useful, content-specific professional development, there is a 27% and 10% lower odds of turnover, respectively.

Teacher Leadership

Teacher leadership emerged in schools and districts over the past few decades as a means of addressing the isolated nature of teaching and the desire to increase teacher status (York-Barr & Duke, 2004). The concept of teacher leadership came to fruition in schools with school accountability (the process of evaluating school performance on the basis of student performance measures) as teacher leadership was seen as a way to improve teaching (Smylie, et al., 2002). Although there is little consensus around what constitutes “teacher leadership,” it tends to encompass a range of activities: teacher leaders promote changes in instruction, take on administrative duties, or hold a formal leadership role (Neumerski, 2013). Teacher leaders can be consultants, curriculum managers, department chairs, mentor teachers, professional development coordinators, resource teachers, specialists, coaches, and demonstration teachers (Mangin & Stoelinga, 2008). In literature and policy, teacher leaders are often out of the classroom full-time, although some teacher leaders assume leadership tasks in addition to full-time teaching or less often, combine part-time teaching and part-time leadership (York-Barr & Duke, 2004). Teacher leaders are excellent classroom performers and acclaimed for their influence in stimulating change and creating improvements in their schools (Pounder, 2006). Based on a review of two decades of teacher leadership scholarship, York-Barr & Duke (2004) describe the expectations of teacher leaders: they support experienced teachers including being able to assess and prioritize district and teacher needs; they know how to create a positive school culture; they establish positive relationships with administrators; they understand action research and inquiry; they expand colleagues’ instructional methods; and, they offer effective workshops and presentations. This description highlights the ability of the teacher leader to build trust and rapport with colleagues, promote growth, and be a good communicator, which are aspects of transformational leadership (Pounder, 2006).

School Factors that Influence Science and Math Teacher Leaders

Schools that provide better principal leadership and administrative support have lower turnover rates (Ingersoll & May, 2010). One study found that about 70 percent of the best teachers, or those who are so successful they are nearly impossible to replace, make decisions to leave their school that could have been influenced by their principal (TNTP, 2012). In addition, teachers who have limited resources are more likely to depart, as are teachers in schools in which necessary resources were not generally available across the building (Ingersoll & May, 2010).

Teacher leadership is an important contributor to retaining excellent science teachers. Teacher leaders lead from within and beyond the classroom, identify and contribute to a community of teacher learners and influence others toward improved educational practice (Katzenmeyer & Moller, 2001). This point is salient because research finds that when schools give teachers these types of opportunities, they are better able to keep their effective teachers as part of a happy and healthy staff culture. Schools with higher levels of school-wide faculty decision-making influence have lower levels of turnover (Ingersoll & May, 2010). Schools with higher average levels of individual teachers' classroom autonomy have lower levels of turnover (Ingersoll & May, 2010). Research suggests that when principals get to know their teachers' interests and development needs, help them access resources, and give them opportunities to grow their careers and increase their impact, they are likely to keep them teaching and leading at their school (TNTP, 2012).

Research Design

Structure/Agency and Transformational Leadership Practice

This study uses the conceptual framework of transformational leadership as it applies to teacher leadership and combines it with Sewell's (2005) theory of structure as a lens to analyze the data. The knowledge of different schemas and access to resources contribute to the possibilities for transforming science education through enactments of structure, or agency. Agency arises when schemas are transposed and resources are remobilized in a unique way (Sewell, 2005). Collective and individual agency of stakeholders in schools and the ability to coordinate actions with and against others is important when thinking about sustaining leadership practice for reformed science education in classrooms and schools. Teacher leadership practice is an example of teacher agency. Leadership can be "seen" as culture enacted as a set of practices and associated schema, which are defined as beliefs and values. Structures include both schemas and resources. Schematic resources exist virtually in the minds of the teachers and include beliefs and values about science teaching and learning and leadership practice. Material resources include actual material things that give teachers the ability to lead, such as monetary resources (e.g., grant money), access to scientific texts, and time. Finally, human resources as it relates to leadership, include a teacher's access to other professionals with knowledge and skills necessary to transform science teaching and learning. Because transformational leadership is focused on changing structures to improve school conditions I examine the structures that influence leadership practice through a sociocultural lens.

Structure and agency are dialectically related, such that structures influence agency, and agency can lead to transformations in structures. Sewell (1992) proposes ways in which transformation is possible through structural change. Actions can sustain reproduction of structures as well as make transformation possible. The capacity to transpose and extend schemas into new contexts and the capacity to reinterpret and mobilize resources are both examples of agency. I see agency as teacher leadership practice and use this lens to be able to examine science teacher leadership practice as teachers change or reproduce structures related to science teaching and learning in ways that contribute to implementation of reformed science education. In addition, because agency arises from knowledge of schema and access to or control of some amount of human and nonhuman resources, I examine what resources teachers were provided in their school settings and through their professional development programs as a means for identifying structures that support or hinder teacher agency as science teacher leaders. In the following section, I describe the research design, including the context, participants, data collection and analyses.

Context

This study explores the research question within a longitudinal professional development program for teachers and administrators in two federally-funded Math-Science Partnership (MSP) institutes designed to enhance teacher content knowledge and the knowledge of science education research of both teachers and administrators in order to transform practice in schools serving grades 5–12 students. The National Science Foundation (NSF) established the MSP program in 2002 to integrate the work of higher education with K–12 to strengthen and reform mathematics and science education in order to improve student outcomes. MSP projects are driven by partnerships between institutions of higher education and K–12 districts, seek to address issues of teacher quality, quantity and diversity, have visions of participation in challenging courses and curricula and strive for institutional change to sustain efforts (NSF, 2010).

The first program (MSP 1) is positioned at an urban northeastern university. MSP 1 was a collaborative initiative between the university's Chemistry Department and the School of Education, focused on providing in-service teachers with content knowledge, science education theory and model instructional strategies in order to encourage teachers to implement reform-based teaching practices in their classrooms. Additionally, another outcome expected by program administrators was that the graduates would become teacher leaders in their schools and/or districts. Teacher leadership refers to teacher-participants working collaboratively with their colleagues to share their new pedagogical and content knowledge gained from participation in the MSP 1 program (Blasie & Kahle, 2009). In this five-year funding period, the program added this leadership component, focusing on increasing knowledge of the administrators of teacher-participants, expanding distributed leadership practices and developing teacher leadership potential. The stated goal of the program was to develop and continue to nurture science educators who are catalytic at the department, building, and district levels.

Over the last 10 years, MSP 1 has enrolled approximately 400 teacher and administrator participants, representing large urban, suburban, and rural school districts. In this study, I focus on years 6-10 of the program, when administrators began to play a more integral role and leadership became a focus of MSP 1. Approximately half of the participants serve student populations from Title 1 schools, or those schools impacted by Title 1 of the US Department of Education Elementary and Secondary Act which receive funding based on having a high percentage of students from low-income families. Furthermore, participants represent diverse school settings including public, private, parochial, and charter schools from five northeastern states. The professional development program consists of 10 courses, eight on chemistry content knowledge and two focused on the theory and practice of teaching and learning chemistry

MSP 2 is positioned at a private, Midwestern university. MSP 2, now in its fifth year, is a collaboration among the university, field trip sites and the Public Schools. This unique collaboration worked together to establish the advanced degree program and leadership training for teams of high school biology teachers. MSP 2 was designed to enhance content knowledge and pedagogy, through a blend of life sciences research and content and science education research and methods. It consists of two three-week summer institutes at the university focused on disciplinary content and online coursework during the academic year focused on pedagogical strategies for incorporating new content into teachers' classrooms. The program also aims to develop science teacher leaders. To this end, the program instituted a leadership program, which continues to engage teachers upon graduation.

Over the last 5 years, MSP 2 has enrolled approximately 110 teacher participants, representing urban, suburban, and rural school districts from all over the United States. Criteria for selection included certified teachers with at least three years teaching experience, some leadership experience and/or leadership potential. The stated goals of the program were to develop a national cadre of master teachers who demonstrate intellectual engagement with, and master of, global issues in life science, and who use related research-based pedagogy and challenging content in their courses. The program also sought to promote partners' and participants' development as local and national educational leaders.

Participants

The participants in this study were 186 secondary science and math teachers who participated in MSP 1 or MSP 2 from 2006–2011. Participating teachers were from large suburban school districts and city school district in equal numbers, with a very small number of teachers from rural districts across the United States. Interview data was collected from a smaller group of science teacher leaders from MSP 2 who participated in a leadership project in the summer of 2011. These four teachers, representing four different states, developed a plan for a teacher led, collaborative professional development to take place during the summer following a leadership retreat. In this teacher-developed model, teachers met in a central location, shared a classroom and piloted case studies, and participated in structured reflection and collaborative feedback.

Data Collection and Analyses

Multiple sources of data were used to investigate the research question as a means for triangulating the data. The survey was used as a larger pool of data, which included all participants from MSP 1. E-portfolios, leadership essays, and interviews from science teachers in MSP 1 and MSP 2 were selected as a representative set of teacher participants. These data were coded for the initial themes related to *constraints* and *affordances* to teacher leadership using a qualitative computer program called *Dedoose*. After tagging excerpts with these parent codes, I then further categorized these excerpts by attaching nested codes based on themes that emerged from the data. During this part of the analysis, the following categories emerged: *administrator support, professional development, seniority, time, recognition* and *money*. These categories fit within the theoretical framework because they are related to specific material, human, and schematic resources that empowered teachers to exhibit agency or leadership practice. Convergence of the data was used as a method for corroborating findings and divergence of the data allowed for surfacing contradictions.

Findings

Data analysis revealed that structures, macro (federal policies), meso (school-based) and micro (MSP program cohort), influenced teachers ability to be agentic or expand their leadership practice. It is important to remember that structures—embodied schema and external resources—both come into being as a product of teachers' agency but also these structures in the world make teachers' agency possible (Roth, 2007). In the sections that follow I outline specific structures—both schematic and material—that influenced teacher leadership practice (agency) and explore examples of agentic actions that transformed or reproduced structures in classrooms, schools, and school districts. This section that follows describes specific structures that hindered teacher leadership practice. In addition, I describe specific structures of the professional development that afforded teacher leadership and hone in on the ways in which a specific structure—administrator support—mediated teacher leadership practice in their schools and districts.

Claim 1: Participation in PD Afforded Leadership Practice

MSP programs are focused on meeting national needs for teacher leaders who have deep knowledge of disciplinary content for teaching and are fully prepared to be intellectual leaders in their schools and districts. MSP 1 and MSP 2 specifically recruited and accepted science and math teachers they considered leaders or who had the potential to develop into leaders. The leadership components of the MSP programs were structured to provide teachers with multiple coordinated experiences to help them build intellectual capital, confidence, and the communication skills necessary for them to be resources for their peers and their profession. The MSP programs provided a field in which science teachers, science faculty, and education faculty came together to construct professional education. A field is site at which culture is enacted (Roth et al., 2004). The goal of the MSP programs was to afford teachers the opportunity to explore new resources and schema to expand their options for action and encourage transformational leadership practice.

The science and math teachers participating in the professional development provided by the MSP programs demonstrated expanded agency. Agency refers to the teachers' capacity to act. Analysis of surveys, electronic portfolios, and interview transcripts revealed that specific structures of the MSP programs gave teachers the opportunity, knowledge, and skills needed to access and appropriate resources. In some instances, teachers were able to engage in leadership practice because of unique structures they reported as being important for encouraging agency. Teachers in the MSP programs were empowered to act because they had access to resources and knowledge of schemas that allowed them to apply these resources in new contexts.

Teachers described their leadership practice, providing descriptions of various human, material, and schematic resources that expanded their agency. Many teachers referenced material resources provided to them through involvement in the MSP programs as a contributor to their leadership practice. The resources provided to teachers through their involvement in the MSP programs included earning a degree, obtaining knowledge, increasing confidence, and participating in leadership activities promoted by the program (e.g., presenting to colleagues, applying for grants, submitting proposals to national conferences). One specific teacher spoke about these resources as a "sling full of science arrows" they could use to shoot around their building and district.

The MSP programs provided teachers with a new definition of teacher leadership that empowered teachers to exercise professional responsibility and enact expert knowledge of teaching and learning:

> Before [MSP1] I thought I was a leader, but by my own definition, I was not acting as a leader. (MSP 1 teacher, e-portfolio excerpt, 2008)
>
> I learned that teacher collaboration is a form of leadership. When two or more teacher's work together or share ideas or just talk respectfully and reflective about their experiences they are exercising a type of grass roots leadership (MSP 1 teacher, e-portfolio excerpt, 2007)
>
> This program has impacted my leadership in my building a great deal.
> It has exemplified what a leader is and the many roles leadership has.

> When I first began I had no idea that teacher leader wore so many hats. I always was led to believe it was a formal role rather than an informal. I soon learned that I indeed was an informal teacher leader. (MSP 1 teacher, teacher leadership survey, 2009)

Although teachers came to the program able to list specific leadership roles and with a particular definition of leadership in mind, the MSP programs influenced teachers' definitions of leadership and helped teachers to identify and reflect on their actions and how they align with personal definitions of leadership. The MSP programs emphasized the importance of collaborative leadership and teachers engaged in the program began to develop a new schema about leadership practice. Teachers in this study began to develop a new understanding about what it means to be a transformational science teacher leader as a result of participating in the MSP programs. This schematic shift gave teachers the knowledge necessary to act as leaders in their schools and districts:

> The professional educator assumes leadership roles and communicates with colleagues and other professional educators the analysis of their own practice (orally and in writing) so that they become catalytic in improving teaching and learning in their schools, districts and/or state… my leadership skills have improved not only for evidence to pad a resume, but I used research as a means to make effective decisions about learning objectives, teaching strategies and to conduct action research on my own practice (MSP 1 teacher, e-portfolio, 2008)

This teacher speaks to the importance of working with others to make changes through restructuring and improving school conditions, which embodies the conception of transformational science teacher leadership. This narrative indicates how the teacher used her expanded agency to establish new structures based on her participation in the program.

The MSP programs also influenced the leadership activities in which teachers engaged. For example, there was a prevalence of self-reported participation by teachers in the professional development of others. In the MSP programs, teachers were given the opportunity to develop and present professional development workshops and encouraged to take these back to their schools. The MSP programs likely contributed to the large number of professional development workshops given by teachers throughout their participation in the MSP programs. Examples of this specific leadership practice as cited in the survey indicated that the professional development teachers referred to was used both as an assignment for the MSP program as well as taken back to schools and districts:

> By presenting PD to my cohort I have gained the confidence to become a teacher-leader in my own district and have made the first steps in formally sharing my knowledge, experience, and vision of science ed. (MSP 1 teacher, e-portfolio excerpt, 2009).

Other teachers noted that the MSP program encouraged them to develop professional development presentations for their classmates in the program that they not only took back to their schools and districts, but also presented as part of pre-service teacher education courses and at national conferences.

In both MSP programs, specific structures, embedded in the program design, afforded leadership practice. In MSP 1, the electronic portfolio was a structure that catalyzed change in teacher practice and supported teacher leadership. By requiring documentation of growth in leadership, as defined by the MSP as "becoming catalytic in improving teaching and learning in their schools, districts and/or state," the MSP encourage program faculty to provide examples and afford all teachers the opportunity, regardless of their school context. In addition, action research was a key component of both MSP programs. Teachers were able to engage in action research that promoted school change and improvement (York-Barr & Duke, 2004):

> So, I think being able to know where the problems are, do the action research in your classroom and share that research out, not just locally, but to anyone who is at a conference to listen to it, I think those are important tools for a leader to have so you are always driving the profession forward (MSP 2 teacher, interview, 2013)
>
> I wouldn't have presented at conferences were it not for this program. And had I not presented at conferences I wouldn't have realized that people are actually interested in what I do. And were it not for the presenting I wouldn't have people from across the state emailing me asking about content and curriculum. (MSP 2 teacher, interview, 2013)

Action research was a structure that promoted teacher agency and spanned across fields. This course requirement translated across weak field boundaries (Sewell, 1999), facilitating teachers to act as leaders in their own classrooms and schools, as they did within the MSP programs. Action research projects structured the classroom and school environments in new ways and allowed for teachers to act as leaders. In addition, teachers were encouraged to share the outcome of their projects beyond the boundaries of their schools and districts in order to drive science education reform and contribute to the profession. Empowering teachers to be transformational teacher leaders has implications for redesigning of school culture, structures, and policies in ways that can improve teaching and learning of science.

As a contradiction to this, the structure of these MSP programs may have limited the scope of participants' leadership practice. The e-portfolio scoring rubric provided examples and suggestions as guidelines for teacher participants. In addition, program faculty encouraged teachers to participate in coursework they saw as demonstrating teacher leadership. This may have constrained leadership practice by limiting the ways in which teachers conceptualized leadership practice or focusing teacher enactment of leadership practice on a narrow set of activities. This limited schema—perceptions and beliefs developed as a result of this experience—constrained agency in some cases. For example, in analysis of survey responses almost all MSP 1 teachers were able to describe in detail the positive impact they had on other teachers they had contact with based on their participation in the MSP program. However, when asked about the leadership activities they led based on participation in the MSP program, teachers commonly reported not having led any leadership activities. When the teachers were specifically asked about their "leadership" they did not mention all of the varied activities that count as leadership due to a limited perception of this practice. The content specific leadership emphasized by the program hindered some teachers' ability to see themselves as leaders:

> My experience in the MSP program does not transfer over to 1st grade teaching. (MSP 1 teacher, leadership survey, 2008)

This science teacher saw leadership as inextricably connected with the secondary science content and pedagogy promoted in the MSP program and was not able to expand on this definition in ways that empowered her to act in her particular context. Teachers limited purview of science leadership practice constrained their ability to act in ways that did not align with those practices promoted by the MSP programs. In the next section, I describe additional context-specific structures that emerged as key constraints to teacher leadership practice.

Claim 2: Specific Structures Hindered Leadership Practice

The teachers participating in the MSP programs demonstrated expanded agency throughout their participation in the program. However, despite their participation in thoughtful multi-year programs focused on developing teacher leaders, participants in the program were not always empowered to access and appropriate resources in ways that demonstrated their leadership practice in their own schools and districts. Specific structures emerged as key constraints to teacher agency. In the section that follows I describe each of the following hindrances with the lens of sociocultural theory: seniority, time, recognition, and money.

Seniority. Seniority emerged as a structure that constrained teacher leadership practice. Despite the examples of leadership science teachers exhibited through participation in the MSP programs, in their own school context, they were actors in a different field. Seniority is a form of symbolic and social capital that allows for more veteran teachers to act as leaders in their field than newer teachers. This particular structure is related to schema—a belief about what is valuable in teaching. This schema suggests that years of experience, number of years at a particular school and age are important indicators of the credible knowledge of teaching and learning that teachers have to share with others:

> I was sort of placed to the side because it was my first year in this new district... (MSP 1 teacher, leadership survey, 2008).
>
> I have not done any voluntary, self-initiated leadership activities this academic year mostly in part because I started a new job at a new school this academic year. (MSP 1 teacher, leadership survey, 2008)
>
> I am currently new to the district. Without proper certification, I am unable to perform science leader positions (MSP 1 teacher, leadership survey, 2010)

In this case, seniority hindered teachers' ability to act and constrained their ability to appropriate the resources from the MSP program in a new situation. Being positioned as a "new" teacher produces differences in power that had implications for how science teachers experienced agency (leadership practice).

Time. Analysis of the data revealed that science teachers' ability to act as teacher leaders was constrained by how time was used and valued in their individual districts. Although teachers had gained valuable resources as participants in the MSP programs, they were unable to appropriate these resources in a different context.

Science teachers felt that the time related to leadership activities was not valued and that other tasks were prioritized:

> The administration of my school has shared some of my classroom practices with principals and academic vice-principals throughout the district. As a result, I was asked to present information to these groups at a district meeting for academics in February. Although I was excited about the opportunity, the meeting was cancelled and never rescheduled. (MSP 1 teacher, leadership survey, 2008)

Additionally, as teachers went back to their schools, even when they were seen as leaders by others in their building they were constrained by a lack of time to be able to meet their goals of being a science leader:

> I have not had the time to get very involved in other leadership activities this year (MSP 1 teacher, leadership survey, 2009)
>
> The principal has suggested that I take the lead teacher position after my supervisor left for a position at another school. I, however, do not have the time to take on this responsibility at this point, and I declined. (MSP 1 teacher, leadership survey, 2008)

Time was both a virtual and actual resources. As a schema, time was seen as something that could not be appropriated differently. Instead of reorganizing or prioritizing time differently, teachers saw time as a hindrance to exercising agency as a science teacher leader.

Recognition. The analysis of data suggested that in order to promote science teacher leadership practice, teachers sought recognition for the work they were doing to contribute to their profession, support other teachers, and improve student achievement.

> Big commitment with little extrinsic reward to prepare and present these presentations but it is the role of a science leader to spread good pedagogy and encourage reflective practice of teachers in the area. (MSP 1 teacher, e-portfolio, 2008)
>
> You know, saying NOYCE Master Teacher Fellow, that will open some eyes in my district. Saying editor/publisher of case studies will open some eyes. You know I think those pieces are really important to have that external validation (MSP 2 teacher, interview, 2011)

These comments demonstrate the schema teachers had about the value of external recognition, which led them to choose leadership activities that were seen as legitimate. This schema drove teachers to seek out specific roles as science teacher leaders (see Chapter 5) and prohibited them from exploring more collaborative, informal leadership practices that were not externally rewarded.

Money and supplies. Actual resources, such as money to purchase materials and access to laboratory equipment, can serve to constrict teacher agency.

> I started the search process with my supervisor to get a new textbook for 8th grade physical science. I have explored several on-line and resource rich materials. Budget woes is slowing this project down. (MSP 1 teacher, leadership survey, 2010)

It is important to understand the access to material resources (equipment, budget, instruments) available for teaching and leading science at individual teachers' schools in order to understand how this can constrain or expand their options for acting as science teacher leaders. Many teachers had difficulty locating money to purchase materials or the equipment suitable for conducting inquiry-based teaching and learning, which could support them as they sought to lead from within and beyond their classrooms.

Summary

In this section, I have summarized specific categories that emerged as hindrances to transformational teacher leadership practice. For science teachers to be able to immediately apply the tools from their professional development experience, it is important to examine associated schema and resources in a new field (e.g., their own classrooms and schools). This set of schema and resources constitute structures that constrained science teachers' ability to act as leaders, even as they developed capacity to lead through their participation in the professional development programs. Although some teachers were able to transpose the resources from the MSP program to their own classrooms, schools, and districts, the structures above hindered the capability of all teachers, regardless of context, to equally act as leaders. This point is salient because teacher leaders who experience a lack of access to resources are likely to leave their particular school context and seek out different opportunities (TNTP, 2012).

Claim 3: Teacher Agency Mediated by Relationship with Building Administrators

Based on analysis of survey data from MSP 1, there was an overall lack of support from administrators for transformational science leadership practice. When teachers reported leadership activities that they initiated, only a small number of teachers indicated there was no leadership activity to report. However, when the teachers reported activities suggested by their administrator or colleagues, 20% of teachers reported “none,” “N/A,” or “not applicable.” Administrator support of science teacher leadership is vital for supporting and encouraging teachers to enact changes in their classrooms, schools and districts (Spillane et al., 2001) and necessary for empowering and retaining excellent science teachers (Ingersoll & May, 2012). Some teachers indicated that administrators often need to suggest or offer opportunities for them, but often fail to do so, leaving teachers feeling powerless to enact leadership practice in their own schools:

> At my last position, I was not permitted to do any self-initiated activities; all needed to be facilitated by my supervisor, or, in some cases, lead by my lead teacher, but approved by the supervisor. (MISEP E, Leadership Survey, 2008-2009)
>
> There is nothing to volunteer for. Everything is delegated by administration. (MCEP E, Leadership Survey, 2009-2010)

These results suggest that although these teachers had leadership potential, as indicated by their participation in the MSP, they encountered obstacles because of aspects of the structure of their schools and districts. Administrator support in initiating science teacher leadership is an essential structure for promoting teacher leadership practice. The large number of responses indicating that teachers have not done any leadership activities suggested by administrators indicates that there is a need for administrators to better support science teacher leadership. Administrators who identify opportunities or paths for teacher leader roles and put their best teachers in charge of something important are likely to hold on to these teachers for twice as long (TNTP, 2012).

Turn	Speaker	Dialogue
01	Interviewer	What do they do that makes them a good leader?
02	Gerry	To be a good leader I think you should be a good teacher, but there's people in leadership roles all the time that aren't good teachers
03	Douglas	People can promote a culture of shared leadership…they recognize that one person can't have all of the skills and understanding to make all the decisions that are needed in a school. A good leader is deeply compassionate and empathetic with kids
04	Rhonda	I think administrators that measure life science teachers they at least need to have at hand how are these important concepts being met
05	Amelia	The first big question is if they understand science or not…cause you want an evaluator to know something really different depending on whether they understand science or not. Are they evaluating you, usually a principal doesn't know anything about science so they're evaluating you generally as a teacher and on some other pieces. They don't really have any idea if you're teaching good science or not

In the excerpt above, the interviewer asks teachers to talk more about administrators who they saw as good leaders. Rhonda and Amelia (turn 04 and 05) focused on the administrator as pedagogical leader and spoke to the importance of content-knowledge for this leader. This aligns with research that suggests that administrators' leadership content knowledge (LCK) is critical to their effectiveness as school leaders (Stein & Nelson, 2003) and their ability to support teachers (Spillane, Halverson, & Diamond, 2004). Douglas provided a definition aligned with a distributive leadership model, where formal leaders, teacher-leaders, and others take responsibility for the work of leading and managing (Spillane & Diamond, 2007). Gerry maintained that a good leader should be a good teacher, but lamented that this is not always the case. Together, the teachers identified knowledge, skills and dispositions that were representative of administrators that were able to support them to teach and lead in their buildings. Administrator support is key for retaining top science teachers (TNTP, 2012).

Some teachers indicated that their administrators were extremely supportive of their leadership work:

> I shared my action research with my principal, who suggested that I continue my research into next year. (MSP 1 teacher, leadership survey, 2009)

> The Principal suggested all the science teachers in our building participate in a 3 year Department of Education Study to examine effectiveness of science teacher methods. I have volunteered to take part in that study which will focus, in Philadelphia, on 7th grade science teachers and their methods of teaching the Cells and Heredity Unit. (MSP 1 teacher, leadership survey, 2009)

Other teachers suggested that though support from their administrator was welcome, it was not necessary, for them to do their jobs:

> I think when it comes down to schools, the leadership, as far as the administration, kind of sets the culture. And even if you've got teachers that are willing to go out there and share, if that's not supported by the administration, it's going to be real difficult to get those ideas out there. Unless you have someone like me last year. I didn't really care what my administration thought. I knew what I needed to do as a professional to try to make the biggest difference not only for my students but also for students that I didn't have contact with by trying to share information with their teachers. [The role of a principal] is not being a hindrance. (MSP 2 teacher, interview, 2013)

Although most of the data pointed to the importance of administrator support for leadership practice, this teacher suggests that support from his administrator was not necessary. Rather, as long as he recognized the importance of science teacher leadership, he was motivated to seek out opportunities. This teacher suggests that for some teacher leaders they might just need an administrator that does not get in the way of science leadership practice. Notably, this teacher ended up leaving the first school to seek out another opportunity where he was recognized for his accomplishments and given the opportunity to act as a teacher leader

Overall, the relationship between the administrator and science teacher had an important role in mediating teacher leadership practice. When administrators were neutral but teachers felt empowered, teachers were still able to accumulate enough resources in order to enact leadership practice, despite this lack of support. However, in some cases a lack of support from the administrators was enough to thwart science teacher leadership completely. This finding is in line with research on science and math teacher retention, which suggests that the principal plays an important role in helping teachers to access resources and giving them opportunities to grow as leaders (TNTP, 2012).

Conclusions

Teachers' access to and appropriation of reform-based science leadership can be shaped in various ways depending upon the schemas and resources present within the field in which culture is being enacted. A person's agency or ability to act is shaped by, and simultaneously shapes, structures (Sewell, 1992). As a teacher experiences professional development, she is able to access new schema and resources. This can lead her to develop new schema and resources and apply these structures within the new context of her classroom or school. Instead, the teacher can learn to use her existing structures in a new way. Finally, the teacher's agency may be truncated such that she is unable to act creatively and instead reproduces the same teaching practices or leaves teaching to put the schema and resources to use in another social position.

My analyses suggest that professional development programs focused on content, pedagogy and leadership, such as the MSP programs, can provide a field that expands teachers' schema and resources. Consistent with the work of Loucks-Horsley and others (1998), this study indicates that science teacher professional development programs can make it possible for science teachers to act as leaders when they accumulate resources and are given access to new schemas about what it means to be a science teacher leader. Specific structures of the MSP programs, such as the electronic portfolios and action research projects, provided teachers with the capacity to act with and against others to promote reform-based science teaching and learning in their own context. As teachers became more knowledgeable about reform-based pedagogy and leadership, they were more likely to take this new knowledge and share it with others. Since many science teachers do not enter teaching with adequate pedagogical education (Ingersoll, Merrill, & May 2012), the MSP programs were instrumental in providing teachers the opportunities to develop schema and accumulate resources they could access and translate into action as science teacher leaders. Consistent with research on teacher leadership, science teachers in this study took part in school-wide decision-making, mentored other teachers, developed curriculum, facilitated professional growth of teachers, participated in action research, fostered more collaborative working arrangements, and influenced school change (Greenlee, 2007; York-Barr & Duke, 2004). The experience in the MSP programs afforded teachers the agency to act and empowered teachers to participate in leadership practice that encouraged them to teach and lead from within their classrooms (Ingersoll & May, 2010; TNTP, 2012).

Evidence in the research literature suggests that transformational leadership makes a difference in educational settings and that positive outcomes of this form of leadership are mediated by factors such as teacher commitment, instructional practice, or school culture (Hallinger & Heck, 1998; Leithwood, Jantzi, & Fernandez, 1994). Extending transformational leadership from the leadership of the building principal to teacher leadership (Pounder, 2006) can develop capacity and commitment of teachers and students, increase teacher agency and ultimately lead to improved student outcomes. Despite the potential power of transformational science teacher leadership practice, teachers engaged in the MSP programs were not universally empowered to appropriate structures in their schools in ways that enhanced leadership practice (agency).

Some science teachers lacked agency in their new field (e.g., their own classrooms and districts) to adopt reformed-based science leadership practice. Seniority, recognition, time, money and supplies all served as barriers that prohibited teachers from reinterpreting and mobilizing the resources in terms of the cultural schemas promoted by the professional development experience. For example, in order to expand teacher agency in relation to seniority, we need to see a change in schema (beliefs and ideology) about what it means to be a good science teacher leader. Even if teachers are young or new to their building or came from alternative programs, this should not be seen as a reason to disempower them from leading a community of teacher learners and influencing others toward improved science teaching and learning. Similarly, science teacher education programs need to consider how to work with schools and districts to promote and recognize science teacher leadership practices in ways that inform teachers they are high-performing, put them on a path for a leadership role, and recognize their accomplishments and contributions (TNTP, 2012). Time served to hinder teachers from truly practicing transformational leadership. Although teachers were invested in growing as science teacher leaders, they recognized limitations of their ability to enact leadership practice based on the prioritization and valuation of available time. Finally, money and supplies, impeded teachers as they sought to enact their leadership practice. The

MSP programs provided resources, such as mini-grants to support specific teacher-led projects, to try to overcome this obstacle. However, some teachers did not have the laboratory space, or were not able to access necessary resources to sustain their projects after the life of the grant. In order to boost science teacher retention and build a culture of distributed leadership, teachers must be provided with access to resources for their classroom (Ingersoll & May, 2010; TNTP, 2012).

In order for teachers to thrive as science teacher leaders, teachers need structures that support learning and leading as embedded aspects of their roles (Darling-Hammond et al., 1995). When administrators fail to provide incentives (Little, 2003; Smylie & Brownlee-Conyers, 1992; TNTP 2012) or do not provide adequate time for collaboration learning and leading (LeBlanc & Shelton, 1997; TNTP, 2012) this can thwart a teacher's agency to enact science leadership activities. According to Smylie and Hart (1999), the principal plays a vital role in the development and maintenance of social capital among teachers and plays an active role in fostering productive social relations within the structures they may help create. The enacted support of teacher leadership by the administrator is an important structure that can support or hinder science teacher leadership. This study found a variety of levels of administrator support, from very supportive, to neutral, to unsupportive. When administrators were supportive, teachers were more likely to put themselves on the line, volunteer to lead through professional collaboration, development and growth (Pounder, 2006). When science teachers were able to share their knowledge and capabilities (e.g., through action research), teachers were able to accumulate the social power necessary to be agentic as transformational science teacher leaders. Supportive administrators provided teachers with material and virtual resources that empowered teachers to act, such as access to a budget for materials, a school culture supportive of reform-based science teaching and learning, chances to collaborate, and opportunities for teacher leaders roles. When administrators were not supportive, even if they were neutral, teachers lacked the transformative capacity necessary to lead pedagogical change for science reform. In addition, when administrators were not supportive, science teacher leaders would have their agency truncated and feel disempowered. Consistent with Ingersoll & May (2010), I found that this led science teacher leaders to seek out other professional opportunities that provided the structures necessary to promote their capacity for agency.

The notion of access to different kinds of resources was used to better understand what teachers need and draw upon in order to act as transformational science teacher leaders. As this study illustrates, some teachers were able to enact science teacher leadership practices by using and adapting resources and schemas associated with the MSP programs in their own classroom, school, and district environments. However, specific structures, both actual and virtual, in teachers' school environments created different opportunities for teachers to enact agency. The action of the school administrator was a key factor in determining science teachers' capacity for agency and transformation of structures for promoting science education reform. In the next section, I discuss implications of this research for science teacher education, K-12 education, and research.

Implications

This research examines what resources teachers were provided in their school settings and through their professional development programs as a means for identifying structures that support or hinder teacher agency as science teacher leaders. This examination demonstrates that professional development programs, such as the MSP programs, can encourage science teachers to accumulate the resources and develop associated schema necessary to act as leaders. However, this research also raises questions about how teachers are able to enact agency in a different field, such as their individual classrooms, schools and districts. The school context for science teacher leaders varies as does the level of administrator support. This gives some teachers the ability to be leaders within and beyond the classroom, while other teachers bump up against structures that truncate their agency causing them to seek out opportunities elsewhere.

As science teacher educators, we need to develop professional development programs that provide opportunities for teachers to discuss strategies for action that can serve as resources when teachers bump up against structures that hinder their ability to enact science leadership practice. In addition, these programs must find ways to overlap with school structures in ways that allow schema and resources to be usefully applied across contexts. For example, science teacher professional development programs should include administrators. In addition, these programs might enroll multiple teachers from a particular school in order to build capacity for social capital through power in numbers. Similarly, programs might look for ways to embed themselves in schools or districts in ways that provide an overlapping field boundary. Only when programs external to schools can find ways of working together to examine issues of practice, resources, and schemas, will science teacher leaders be able to use their newly developed knowledge and skills. This work is essential if we want to empower science teacher leaders in ways that encourage them to stay in the classroom, especially in our most disadvantaged schools where turnover is even higher.

In addition to rethinking structures of professional development programs, we should consider how school systems might change in order to provide opportunities for teachers to enact leadership practice. Consistent with findings from The New Teacher Project, excellent teachers who experience regular feedback, are recognized for their contributions to the profession, are given opportunities or paths for teacher leaders roles, and are provided with access to additional resources for their classroom are more likely to remain in the classroom. In the section below, I outline some school-based models that could support science teacher leaders.

School-Based Models that Support Science Teacher Leaders

Teacher-led schools, also known as teacher-run or headless schools, are schools that operate without a principal or central administrator (Myers, 2013). Teacher-led, teacher run schools are a relatively new reality in public schooling. A teacher-led school has autonomy, similar to charter schools, where it has the ability to run its budget, select its faculty, and decide what approach to learning will work best for its students. These schools represent a model where teacher vision and voice are the least encumbered by hierarchical leadership models. The goal of these democratic schools is to promote a sense of ownership, satisfaction, financial stability, and engagement with the broader community (Myers, 2013).

One example of this is the Math and Science Leadership Academy (MSLA) of Denver, Colorado. This public, teacher-led school is working to meet the needs of a diverse population by redefining traditional teacher and administrator roles. The school opened in 2009 and currently serves grades K-3. The school's staff of teachers who, in addition to teaching for at least a portion of their day, also fulfill the administrative duties typically performed by principals, curriculum specialists, and mentors. This model seeks to build collaborative teacher leadership in order to create a culture in which teachers and students are active and empowered. Since the opening of the MSLA, many other teacher-led schools have opened and continue to open. These schools are still relatively new, but the model may address new conceptions of teacher leadership.

In addition to teacher-led schools, some charter schools are redefining teaching and teacher leadership by creating content leadership roles and teaching continuums. Charter schools have more autonomy and typically less support than traditional schools from dedicated departments in the central office for curriculum and assessment. Therefore, charter schools tend to rely on their effective teachers to do much of this work. Charter schools, such as YES Prep and the Knowledge is Power Program (KIPP), place the power of writing curriculum and assessments in the hands of the innovators in the work, their teachers. Teacher leaders with extensive classroom experience and a track record of success can hold content leadership roles. In these roles, teachers may be given a reduced course load in order to prepare exemplars, support teachers, and produce professional learning for their content area across the school. In addition, they are given a title, such as Director of Content, Content Specialist, or Course Leader, and compensated for this work.

In addition, the autonomy given to charter schools, allows them to define how teachers are compensated. Charter schools develop models for paying teachers based on value-added, not years worked. The goal in having this continuum is to reward great teachers and create teacher leadership pathways where the most effective teachers can continue to grow without leaving the place where they are making the greatest impact—the classroom. These models seek to keep the most talented teacher leaders in the classroom. In order to do this, schools define a framework for compelling compensation options for teachers. At YES Prep in Houston, TX they have developed a continuum with six levels of teachers. Years of experience, as well as student achievement in their classroom, and other indicators of effective teaching, define each level. Each step on the continuum is associated with a different salary range. Teachers may hold a role as a novice teacher ($44K), developing teacher ($46-50K), practiced teacher ($54-64K), advanced teacher ($66-80K), and master teacher fellow (+$10K above base and/or significant release time). This continuum rewards strong performance and provides a means by which each teacher can enjoy both recognition and reward for the time they spend working directly with students.

Since leadership practice is culture, cultural alignment is essential for allowing for successful interactions that afford success and facilitate learning. As policies and programs continue to promote science teacher leadership, it is critical that we recognize the importance of a shared definition of transformational teacher leadership for facilitating positive interactions that improve science education. Research and practice must find ways to recognize science teachers as professionals by providing science teacher development and school-based programs and associated structures that promote transformational science leadership practice, which encourages our best science teachers to teach and lead in their classrooms and beyond.

CHAPTER 7 – IMPLICATIONS

Introduction

In order to create sustainable science education reform, we must provide ongoing education to teachers and their administrators that support their understanding of science content, pedagogy, and leadership as well as promote school structures that empower our science leaders to create pedagogical change.

The overall research questions that guided this study were:

1) How does a PD program for administrators and teachers influence administrator and teacher science leadership for reform in schools and within districts?
    a. Who am I in relation to this research study? (Ch. 3)
    b. What impact does a PD program for administrators have on administrators' leadership content knowledge and pedagogic leadership with regards to science teaching and learning? (Ch. 4)
    c. What leadership roles do science teachers play in their classroom, schools, districts, and nationally? (Ch. 5)
    d. What structures support or hinder teacher agency as science teacher leaders? (Ch. 6)
2) What challenges do teachers and administrators face as they try to implement science education reform?
    a. Who am I in relation to this research study? (Ch. 3)
    b. What challenges do administrators face in supporting science teaching and learning? (Ch. 4)
    c. How do teachers define science teacher leadership? (Ch. 5)
    d. What structures support or hinder teacher agency as science teacher leaders? (Ch. 6)

These broader questions were addressed within each chapter, as well as through a subset of narrower questions that served as additional important avenues for inquiry. In this final chapter, I organize my findings through a synthesis of these broader questions in an effort to pull together the results of the study and discuss how they can inform policy, research and practice.

In Chapter 1, I elaborated on the intersection between administrator and teacher leadership and the perceived role of this leadership in science education reform. Although science education reform has been a topic of significant discussion since the late 1980s, progress towards these goals has been slow (AAAS, 2001; NAS, 2005; NRC, 1996; NRC, 2000). One possible reason for this is that administrators and science teacher leaders have not been heavily engaged in these reform efforts. In addition, research on pedagogic leadership in science education is scant. I completed this study to provide insight into the challenges and strategies for building teacher leadership for science education reform through professional development for science teachers and their administrators.

The main findings are chapter specific and were summarized within the respective chapters (3, 4, 5, and 6). In the sections that follow, I synthesize the findings by first discussing the specific model of professional development that was used to develop and support reformed science leadership, by teachers and administrators. I then discuss persistent challenges faced by administrators and science teacher leaders, individually and collectively. While the professional development explored in this research represents a set of exemplary experiences, this chapter also presents a model of professional development intended to address these challenges and the goal of reformed science leadership. Finally, I interpret my findings on a broader scale in order to draw attention to larger structural issues and offer implications for promoting science teacher education policy and practice, improving K-12 school science, and for guiding further research.

Synthesis of Findings

Impact of a Professional Development Program at the Interstices

This dissertation focused on two federally-funded Math-Science Partnership (MSP) programs as the context of the research. Within the MSP program for science teachers, was an embedded professional development opportunity for their administrators called the Administrators' Science Institute (ASI). As part of the study, I wanted to see how teachers and administrators who participated in these programs were influenced related to their reformed science leadership practice. I developed the framework of reformed science leadership by combing the lenses of pedagogical leadership (PL) (MacNeill et al., 2005) and leadership content knowledge (LCK) (Stein & Nelson, 2003) in order to specifically address the leadership practice that promotes science education reforms. Combining the knowledge of teaching and learning science (LCK) with the ability to empower others in order to build collective action for reform (PL) represents the knowledge and skills necessary for a leader to implement reform based science teaching and in turn improve student outcomes in science. Table 14 summarizes the main components of PL and LCK and provides an overview of the framework of reformed science leadership used to focus attention on the knowledge and actions of administrators and teacher leaders for transforming science teaching and learning.

Table 14.

Combining Components of Pedagogic Leadership and Leadership Content Knowledge to Create a Framework for Reformed Science Leadership

Reformed Science Leadership	Pedagogic Leadership	Leadership Content Knowledge
Focus on student achievement based on **knowledge** of science and how science is learned	Focus on students' learning	Focus on how students learn subject matter
Curriculum connected to national, state and local science standards and connected to authentic science problems	Curriculum determined by needs and interests of students and connected to examples drawn from real life/world	Curriculum connected to state and national standards
Predicated on **supporting** the science teaching profession based on knowledge about how teachers learn and teach science	Predicated on teaching as a profession	Predicated on knowledge about how teachers learn and teach subject matter
Promoting science teacher leaders	Distributed leadership	Principal as mentor
Building a **culture** of professional learning based on teaching and learning science	Building a professional learning community	Professional learning focused on coherent, subject-specific instructional guidance
Principal **actions** facilitate learning and evaluate effectiveness of approach based on knowledge of effective science teaching	Principal as leader of teacher professional learning	Principal equipped to observe and assess effective teaching
Moral, facilitative and **collaborative** in nature; Aims to support reformed science teaching	Moral and facilitative in nature	Collaborative and supportive in nature

If a program for administrators and teachers could lead to specific areas of growth for administrators and science teacher leaders, then it could inform other teacher educators and program directors. What I found is that the program design did make some significant changes, but that it was not sufficient for creating pedagogic leaders for science education reform or overcoming obstacles science teachers and administrators faced in their own context. Notably, the biggest impact of the program came from the interstices: the collaborative partnership between teachers and administrators that served to build transformative change.

Growth in capability of administrators. Using quantitative data based on a dependent (paired) t-test of pre- and post-survey results, I found that administrators grew in terms of their specific *knowledge* about how science is taught and learned, as well as in their *actions* based on participation in the ASI. Through participation in specific learning activities, administrators learned about the national science content standards, as well as the national science teaching standards. More importantly, they participated in a series of reformed science lessons, as students and administrators, in order to develop a deeper understanding of the process of engaging in scientific inquiry. This growth in knowledge of the subject matter, and how it is best taught, was critical to the effectiveness of administrators and district leaders as they considered how to support science teachers in their buildings and districts. This finding is consistent with research that suggests that when administrators understand content and how it is best taught they are better able to support teachers and lead pedagogic change (Spillane, Halverson, & Diamond, 2004; Stein & Nelson, 2003). The change in actions related to this new knowledge represents growth in their reformed science leadership practice. Empirical coding of the data (including journal entries, survey data, and video transcripts) revealed five categories of improved action: curriculum and instruction, materials support, classroom culture, teacher feedback and evaluation, and issues of distributed leadership (Table 15).

Table 15.

Growth in Administrator Actions Aligned to Reformed Science Leadership

Category	Growth
Curriculum & Instruction	Supporting teachers to restructure curriculum for deeper understanding
Materials Support	Supporting teachers through budgets and procedures to improve access to science materials
Classroom Culture	Supporting teachers in issues of classroom culture and management during inquiry lessons
Teacher Feedback and Evaluation	Providing aligned feedback for teacher growth disconnected from formal evaluations
Distributed Leadership	Recognizing the need to engage and empower science teacher leaders

As administrators learned more about reformed science teaching and learning they expressed a renewed commitment to supporting teachers based on this knowledge through discussions and school improvement plans. These changes in actions were important because when administrators were more familiar with discipline-specific curriculum and pedagogy they could consider these as they designed professional learning opportunities for science teachers, outlined budgets and strategies for accessing instructional materials, and created systems for providing feedback to support pedagogical change. In this study, I found that the focus of the ASI on science content and pedagogy and on the intersecting area between administrators and science teachers led to actions that could support and promote inquiry teaching and learning in science teachers' classrooms.

Growth in leadership roles of teachers. The MSP programs for science teachers were structured to provide teachers with multiple coordinated experiences to help them build intellectual capital, confidence, and the communication skills necessary for them to be resources for their peers and their profession. Throughout participation in the MSP programs science teachers were given opportunities to increase their capacity as leaders and to develop leadership projects. My findings show that this focus on leadership practice empowered science teacher leaders to be agentic because almost every teacher who participated in the program was able to identify a science leadership role. I analyzed survey data based on the seven dimensions of leadership practice, both formal and informal, based on empirical examples from the literature (York-Barr & Duke, 2004). This analysis revealed that teachers reported activities in all seven categories, but primarily reported leadership activity involving coordination and management, working on curriculum for their schools or districts, and participating in professional development of colleagues.

The structures of the MSP programs—including the e-portfolio, action research projects, leadership retreats, and facilitating professional development during class—were catalytic because they provided human, material and schematic resources that expanded teacher agency. These MSP program structures shed light on science content and pedagogy, while simultaneously engendering sufficient interest and consequence that empowered teacher participants to positive leadership action. Not only did the MSP programs contribute to the roles for science teacher leaders, but it also influenced the way that science teachers defined science teacher leadership. Teachers in this study defined leadership as legitimate science leadership or transformational science leadership. Legitimate teacher leadership describes teacher leadership as activity done to or for others, rather than in partnership, that comes with external validation in terms of title, recognition, or money. Transformational science leadership is done collaboratively and seeks to improve student learning of science and contribute to science education reform. My findings show that as teachers became more involved in the leadership components of the MSP programs, some began to develop a more nuanced understanding of science teacher leadership focused on collaborative efforts to improve understanding of science locally, nationally, and globally. This point is salient because as current policy initiatives are being developed around the idea that teacher leadership involves the day-to-day work of classroom teaching and the ability to exercise transformational leadership with colleagues in order to improve student learning (Teacher Leader Model Standards, 2011).

Collaborative projects. Collaborative leadership projects represented a final area of impact from the professional development programs. During the course of the MSP programs, a subset of teachers and administrator-teacher pairs coparticipated in collaborative action-research projects. Through these projects, teachers and administrators worked together to develop and implement projects that promoted inquiry-based science teaching by focusing on student achievement based on LCK and PL. Through this work a group of teachers collaborated to develop and field test inquiry-based teaching materials and create a professional learning community focused on student achievement. In addition, administrators and teachers collaborated to address a context-specific barrier for implementation of reformed science teaching. These projects serve as an ideal example of how the intervening gap between administrator and science teachers can be bridged in an effort to implement pedagogic change and increase student learning. This finding is consistent with research that suggests when administrators and teachers can form a community dedicated to the teaching and learning of their students they can introduce and sustain education reforms (Silva, Gimbert, & Nolan, 2000). This component of the MSP programs, though only a small part of the program design, had a big impact on increasing the implementation and sustenance of the reform teaching practices learned in the program. This research found a series of positive impacts of participation in the MSP and ASI programs for science teachers and their administrators, but also identified challenges that remained.

Challenges Faced by Administrators and Science Teacher Leaders

Despite the focus of the MSP programs on developing science teacher leaders in partnership with their administrators, challenges to their leadership practice persisted. Individual chapters are focused on administrators (Chapter 4) and science teacher leaders (Chapter 2, 5 and 6), and the challenges that affected them. However, many of the obstacles faced by administrators and science teachers overlapped and were located in the small space between teacher and administrator. The figure below (Figure 16) provides a schematic representation of the challenges faced by administrators, science teacher leaders, and those faced at the interstices.

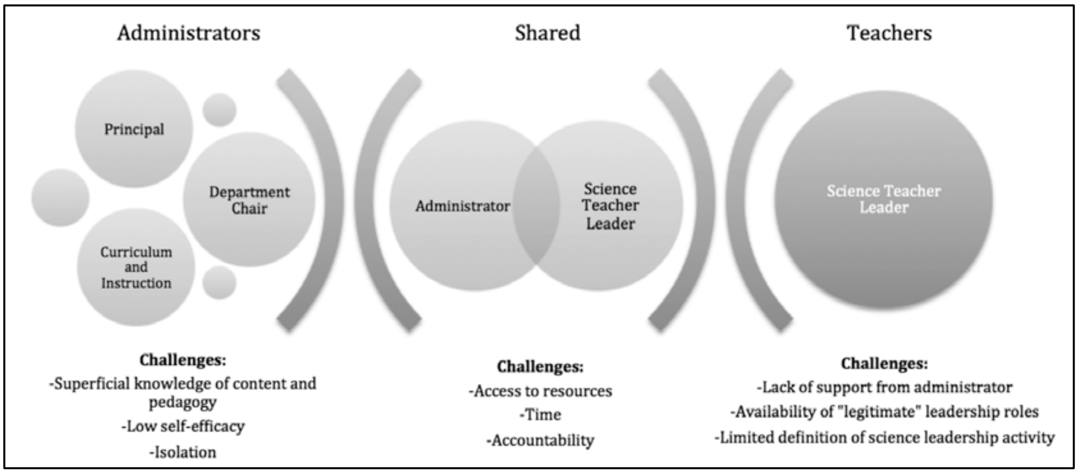

Figure 16. Individual and overlapping challenges of administrators and science teacher leaders.

Administrator-specific challenges. Applying the framework of reformed science leadership, which combines ideas from the lens of both pedagogic leadership (PL) and leadership content knowledge (LCK), I found significant challenges for administrators. Administrators in this study faced major obstacles as they worked with science teachers on implementing inquiry-based teaching practices. Although participation in the ASI led to growth in knowledge of science teaching and learning, their understanding only scratched the surface. This is likely because many of them were not former science teachers and the only experience they had with this content-specific leadership was in this limited professional development experience, providing them with only superficial knowledge of science teaching and learning. Research shows that when administrators lack this understanding they are less likely to be equipped to perform some necessary leadership functions, especially as it relates to pedagogic change (Stein & Nelson, 2003). Administrators' lack of understanding of science pedagogy and content, in this study, led to a low self-efficacy for facilitating content-specific teacher learning. Some related effects included the difficulties administrators faced as they sought to improve the teaching and learning of science through effective teacher evaluation and feedback. In addition, less efficacious leaders reported it was especially challenging to fully support school related tasks—such as facilitating PLCs—associated with pedagogical change. This finding is consistent with similar research examining pedagogic leadership, which suggests that principals with a high self-efficacy orientation and depth of understanding of pedagogy and associated learning and teaching will engage in discussions with teachers on matters pertaining to classroom practice but less efficacious leaders avoid these activities (Silcox & MacNeil, 2006). Additionally in my research, I found that outside of the collaborative projects undertaken by some teacher-administrator pairs, administrators typically operated in isolation, rather than working with other administrators or science teachers who could provide the necessary knowledge of reformed science teaching and learning. This isolation was a challenge because it limited administrators' agency to build capacity for reformed science leadership.

Science-teacher specific challenges. As science teachers in the MSP programs developed into science teacher leaders and sought to lead changes in their classrooms and schools they faced significant challenges. For example, although research supports the notion that teacher leaders have the greatest likelihood to change school-wide instruction (Danielson, 2006; Mangin & Stoelinga, 2008; York-Barr & Duke, 2004), the science teachers in this study did not privilege some of the leadership activities that are likely to have some of the greatest potential for school change. Using the frameworks of dimensions of leadership practice and transformational teacher leadership, I found that science teachers tended to cite leadership activity that could be categorized as coordination and management, curriculum work, or facilitating professional development workshops. These activities include those that have clear leaders and followers and receive recognition that cannot be earned when engaged in more informal, collaborative leadership efforts. Science teachers came to lead based on their own definition of a leader in science education. Although all of the teachers were in a program focused on building capacity for transformational teacher leadership, many of the science teachers in the program still defined leadership as something outside their daily work, based on leading and managing others. Teachers in this study tended to define science teacher leadership in ways that did not align with current policy and practice, focused on authentic, collaborative leadership for student learning. Consequently, as some teachers developed into leaders they were also likely to seek out opportunities to showcase their capacity, especially if they faced barriers to this in their own context.

In this study, I combined the lens of transformational leadership with the theory of structure and agency (Sewell, 2005) to further explore the structures that hindered teacher agency as science teacher leaders. While the science teacher leaders looked for legitimate leadership roles, specific structures emerged as key constraints. Despite the examples of leadership science teachers exhibited through participation in the MSP programs, in their own school context they found that there were limited opportunities available. In addition, many of the roles that were available, such as curriculum coordinators or instructional coaches, required that science teachers leave the classroom. Specifically, administrators of science teacher leaders did not always support them as they sought to enact leadership practice. I found that many of the science teacher leaders in this study were not asked by their administrators to participate in science leadership activities in their schools or districts, despite the expertise they were developing through participation in the MSP programs. This lack of opportunity led to the unintended consequence of some MSP participants leaving the classroom and therefore contributing to a negative impact on science teacher retention. The findings from my research showed that when science teacher leaders were not supported by their administrators, some of them left to seek roles outside of the classroom as a way to legitimize their knowledge and skills or took roles that inadvertently focused on leading from outside of the classroom. The science teachers that left their schools to assume a different position—early leavers—or those that moved outside of the classroom to find a role that recognized their expertise—vertical advancers—continued to contribute to science education reform, but did so in ways that were not intended outcomes of the MSP programs. This research suggests that administrators did not always support science teacher leaders and this lack in support was often related to administrators' inadequate reformed science leadership practice. Research supports the finding that when administrators do not provide adequate support for science teacher leaders, in the form of incentives, time for collaboration, or resources, these teachers leave the classroom for non-teaching jobs both within and outside of the education sector (Ingersoll & May, 2010; LeBlanc & Shelton, 1997; Little, 2003; TNTP, 2012).

In addition to a lack of administrator support, science teacher leaders bumped up against other obstacles within their own school settings. Although science teachers were afforded the resources and opportunities to lead based on their participation in the MSP programs, many teachers still felt they were unable to realize their potential. These science teachers lacked agency in their new field (e.g., their own classrooms and districts) to adopt reform-based science leadership practice. I found that in their own context, teachers were not always empowered to access and appropriate resources in ways that demonstrated their leadership practice. Instead, issues like seniority, the need for recognition, money and material resources, all emerged as key hindrances to leadership practice. This point is salient because the research suggests that when teachers lack access to resources, not only do they not have the opportunity to lead changes in instruction in their schools, but they are also more likely to leave their particular school context and seek out different opportunities (TNTP, 2012). Additionally, if school structures, including schema and resources, promote and recognize science teacher leadership practices in ways that inform teachers they are high-performing, put them on a path for a leadership role, and recognize their accomplishments and contributions they are more likely to remain teaching and lead beyond the classroom (TNTP, 2012). Because research suggests that teacher leaders have the greatest likelihood to change school-wide instruction (Danielson, 2006; Mangin & Stoelinga, 2008; Marks & Printy, 2003; York-Barr & Duke, 2004), a major goal of the MSP programs was to create science teachers who could lead from within and beyond their classrooms. As a member of a cohort from MSP 1 and an involved staff member of MSP 2, I have been in contact with many teachers who left their schools to seek out different teaching jobs that provided more leadership opportunities, advanced to become curriculum coordinators or principals (vertical advancers), or left K-12 education to pursue science education reform through research and teacher education (early leavers). Similarly, my story reflects the trajectory of an early leaver, because after gaining the knowledge of content, pedagogy and science education reform, I sought a role that I felt would better recognize my capability and provide a broader impact outside of my individual classroom. As an early leaver myself, I know that school and district structures were part of what persuaded me to leave the classroom and seek to be a leader in science education reform from the outside.

Shared challenges. While administrators and science teachers faced some challenges unique to their particular role in the school or district, some of the challenges they faced overlapped. One major shared obstacle was lack of time. Both administrators and science teachers cited a lack of time dedicated to activities specific to promoting the science education reform agenda. Although administrators and teachers were invested in practicing reformed science leadership, they recognized limitations of their ability to enact leadership practice based on the prioritization and valuation of available time. Administrators have the added challenge of providing pedagogical support to teachers at different grade levels teaching different subject areas in addition to managing day-to-day operations. The administrators in this study felt that they did not have the time required to develop a sufficient understanding of science teaching and learning. In addition, both administrators and teachers felt that it would take significant time to be able to observe science teaching in a way that aligned reformed science teaching. Finally, both administrators and teachers acknowledged that time was a major obstacle in implementing a culture of professional learning based on teaching and learning science. In this case, time was both a virtual and actual resource that hindered the ability of administrators and teachers to enact leadership for science education reform.

Another challenge for administrators and teachers was access to resources to support reformed science teaching. Even when administrators became more aware of the science equipment and materials necessary for implementing inquiry-based teaching, they were often unable to make these available due to budget deficits and a lack of decision-making control regarding school finances. MSP teachers were able to access resources from the MSP for leadership projects by applying for grants made available by MSP program directors in order to address this obstacle. However, while grant funds made it possible for them to access and appropriate resources in ways that enhanced leadership practice (agency), the funds were only available on a one-time basis. In addition, many teachers did not have the laboratory space or were not able to access necessary resources to sustain their projects after the life of the grant. Research suggests that in order to boost science teacher retention and build a culture of distributed leadership, teachers must be provided with access to resources for their classroom (Ingersoll & May, 2010; TNTP, 2012).

In addition to time and resources, issues of accountability affected both science teacher leaders and administrators. Both administrators and science teachers indicated that they were under pressure to "cover the curriculum" in order to provide the students with the information necessary to meet state and national standards. This pressure made it difficult for both stakeholders to fully actualize implementation of reformed science teaching. Furthermore, the administrators' sense of accountability for everything that happens in a school made them hesitant to relinquish control to their science teacher leaders. This was another reason why science teachers may not have had ample opportunities to enact leadership practice within their schools and districts.

Summary. In writing this dissertation, I have discussed these findings with school administrators, teachers, and teacher educators that I work with. In each case, my colleagues see these challenges that administrators and science teacher leaders face as they seek to enact reformed science leadership. It is important that we consider both the obstacles that administrators and science teacher leaders face as key constraints to implementing science education reform as we develop plans for addressing them through programs and policies. Administrators, teacher educators and policy-makers alike must consider these challenges as they determine how to change current policy and practice in ways that refocus science teaching in order to improve college preparation, STEM career readiness, and students' ability to make informed decisions.

Broader Implications

Although this study represents a small subset of science teachers and administrators engaged in a particular professional development program, the findings can inform further reflection, reform and action. The specific findings described above are relevant to policy, research and practice science teacher education and in K-12 schools.

Implications for Science Teacher Education Policy and Practice

In this section, I present a synthesis of the relevance of the key findings to teacher education. I then answer the questions: (1) What might PD look like that recognizes the multiple pathways for teacher leadership?; (2) How might PD programs support administrators in ways that can overcome challenges?; and (3) How can PD be developed for both teachers and administrators to encourage common experiences and shared responsibility?

Science teacher education. This research suggests that professional development programs for science teachers should consider how to engage administrators in order to promote sustainable science education reform. Programs, like the MSP programs in this study, have the potential for promoting growth in science teachers and administrators that stimulates and supports pedagogical change in science. Ultimately, these programs have the potential for improving student success, as measured by college preparation, STEM career readiness, and their ability to make informed decisions. Research supports this idea because professional development programs have the potential to not only influence the knowledge of teachers and administrators, but also increase the chances for students to meaningfully learn content (Darling-Hammond & McLaughlin, 1999). In addition, effective professional development can stem attrition of teachers (Loucks-Horsley et al., 1998), especially science teachers, who enter the profession with a more limited pedagogical education (Ingersoll et al., 2002).

In my research, I found that the MSP programs developed teacher leaders, but the programs were limited in promoting all types of leadership activity, especially activity that was more collaborative and informal. As discussed in more detail in Chapter 5, teachers saw leadership roles that are externally validated as more legitimate than others and were less likely to define science leadership in ways that align with current policy and practice. The ASI program, focused specifically on developing leadership content knowledge and pedagogic leadership for administrators, was successful at increasing knowledge of science teaching and learning and related actions, but was less successful in changing actions that bumped up against the specific challenges administrators faced. For example, the ASI did not result in an increase in the support of the science teaching profession based on leadership content knowledge in ways that built a professional learning culture, because the limited experience did not provide sufficient understanding of content and pedagogy necessary for this action. The growth and persistent challenges are discussed in more detail in Chapter 4. These limitations would suggest that future science teacher education programs need to provide some of the structures of the MSP programs in this study that led to these positive effects, but also consider adding additional supports to address hindrances to reformed science leadership. In the sections that follow, I outline specific areas that must be attended to if we are to develop science teacher leaders who can refocus their teaching based on the conceptual shifts in the Next Generation Science Standards (NGSS) and well-informed administrators who can support this vision of effective science teaching and learning.

PD for science teacher leaders. Programs for science teacher leaders must consider ways for addressing the content knowledge and pedagogy necessary for promoting exemplary, inquiry-based science teaching. As discussed in Chapter 5, science teacher leaders had limited definitions of science teacher leadership, which influenced their leadership roles. In addition, findings in Chapter 6 suggest these science teacher leaders experienced both affordances, including the MSP program, and hindrances to their leadership practice. As programs consider developing science teacher leaders they must consider how they address these findings. Professional development programs for science teachers might consider the following suggestions as they seek to better prepare science teacher leaders in ways that sustain science education reform:

(1) Encourage definitions of science teacher leader that align with policy and practice

(2) Design the program to promote transformational leadership activities

(3) Provide development that supports some science teachers to move into administrative roles

(4) Partner with schools and districts for ameliorating hindrances to leadership action

PD for administrators. Programs focused on improving science teaching and learning, must also have a component focused on administrators, especially secondary school principals, rooted in a deep understanding of content and pedagogy. In Chapter 4, I describe some of the components of the ASI that led to improved knowledge and actions by administrators as they sought to support reform-based science teaching. However, Chapter 4 also highlights challenges that remained. Based on these findings, programs for administrators should consider both the approach used by the ASI and the remaining challenges to create programs that:

(1) Develop an understanding of inquiry teaching and learning in science classrooms
(2) Build a culture for professional learning and shared leadership
(3) Create a professional learning community of administrators

PD to bridge the space between. More important than professional development programs focused on science teachers or administrators, alone, are programs that can bring together classroom science teachers with their administrators to develop shared understanding. In this model of PD, science teachers and administrators would learn at the shoulders of one another so that their learning can be more easily translated outside the field of the PD to their individual context. This can lead to a culture of coparticipation, mutual respect, and collective responsibility for student learning grounded in common knowledge and shared experiences. The collaborative action research projects in this study were an example of collaborative efforts focused on science education reform. While these projects represented only a small portion of the MSP and ASI program, this research suggests that focusing on developing more robust collaborative learning experiences for administrators and science teacher leaders is a promising strategy for realizing science education reform.

Implications for K-12 Schools

In this section I consider two questions: (1) How can vertical movement of science teachers impact systemic changes for science education reform? and (2) How can K-12 schools create new roles for teachers? These questions emerged from the findings of this study. The first question considers the unintended consequence of building leadership capacity of science teachers—vertical advancement into administrative roles but out of the classroom. The second question concerns those science teacher leaders who build capacity, want to remain teaching, but also seek leadership roles that are legitimate and recognized. The findings in this study used the theory of transformational leadership and structure/agency as a lens for building on current understandings of teacher leadership by focusing on science teachers, specifically, and identifying barriers and affordances to teacher leadership practice (agency).

Vertical advancers. This research provides information about how teachers and administrators interact within their schools to support science education reform. While administrators attempt to support reformed science teaching, their lack of knowledge is a key constraint. If schools are to truly build professional learning culture that builds on knowledge of teaching and learning science, then science teacher leaders are key to this work. This research finds that administrators are rarely former science teachers and have little knowledge about the structures necessary to support science education reform in classrooms, schools and districts. Therefore, science teachers who move into administrative roles can be key contributors to moving the science education reform agenda forward. Instead of limiting the focus of leadership development for science teachers to building capacity through leading from within the classroom, programs should consider how to support science teachers to take their specific knowledge of science content and pedagogy into administrative roles in ways that will fully support their teachers to implement reform. This study suggests that programs should focus on developing science teachers to become leaders not only in their own classrooms, but also as building administrators and district leaders.

New roles for teachers. Teachers come into and stay in the profession because they love their students and they enjoy the art of teaching—pedagogy, content, and creativity. A great teacher is strong in lesson design, execution, building relationships with students and families, and facilitating students to high levels of academic achievement. However, these teachers' strengths often provide them with the opportunity to "move up" into an administrative position and out of the classroom. In the current structure of K-12 schools, there is a deep divide between teachers and administrators—educators tend to be EITHER teachers or leaders.

Teachers put in this position are torn by the decision to leave their students and pursue the intellectually demanding, more prestigious work of administration (principal, dean, instructional coach, etc.) or to stay with their students and give up on an opportunity to lead the direction of their department, building, or district. While the previous section suggests that we want some of these teachers to vertically advance, it is also important that schools create positions, which allow teachers to continue the work in their classrooms, while simultaneously leading in their area of strength. Otherwise, teachers who do not want to move into administrative roles may be become the early leavers to the profession by finding ways to lead that take them outside of their classrooms.

I suggest the need to reconceptualize leadership pathways in schools, such that teachers are provided with the opportunity to be legitimate leaders while still having opportunities to teach. In fact, I would argue that maintaining a strong tie to the classroom makes a curriculum designer, dean of students, or principal better prepared to fulfill their responsibilities in the school because it supports them to “stay in touch” with what the daily life of a teacher looks like while also working within the administrative structures that they are part of to create and enforce policies and curriculum that are effective. Therefore, new models will need to be created to educate teachers about what constitutes leadership, empower teachers to be leaders in their buildings and formally recognize their leadership, so they don’t feel like a classroom teacher with a lot of extra work. In this study, teachers described a model of teacher leadership that was collaborative, student-focused, and recognized by their colleagues and administrators. This calls for the creation of dual roles for teachers. This study supports the creation of what Berry and the TeacherSolutions 2030 Team (2011) refer to as a “teacherpreneur.” A “teacherprenuer” role would allow teachers to remain active in their classrooms part time while also working outside of it, focusing on education policy, research, or community involvement (Berry & TeacherSolutions 2030 Team, 2011).

In order to do this, policymakers, programs, and individual K-12 schools must consider how they might create a dynamic and flexible learning environment for students and teachers that would allow for reimagined teaching positions that combine an element of impacting school change with teaching students. In addition, policies should be developed that might professionalize teaching such that it becomes a well-compensated career with many pathways. In addition, findings from this study suggests that new roles need to be developed for classroom experts, who are not compelled to leave the classroom to share their expertise, but rather who are provided the opportunity to stay in the classroom with a reduced teaching load while simultaneously pursuing research, writing curriculum, occupying a role to influence educational policy, participating as a community organizer or serving as a trustee of the profession.

Implications From My Experience

For me, writing this dissertation made me reconsider what it means to be a leader in science education. When I began this dissertation, I thought that being a leader meant leaving the classroom and having an impact beyond one class of students per year, whether this was as a district curriculum coordinator, a school principal, or a science teacher educator. As I complete this chapter I recognize that science leadership is crucial at all levels and is likely even more influential when leading from within the classroom.

When I first decided to pursue a doctorate, I entered a full time Ph.D. program. The disconnect from schools was palpable from the beginning as I sat in courses taught by professors who had not been in local schools in over 30 years. How can we study education, inform policymakers, and teach future teacher educators, if we are removed from the day-to-day realities of teaching? For reasons both personal and professional, I transitioned from a full time program into a part time program. My new position brought back in touch with science teachers as I taught in Master's and certificate programs for science teachers. It brought me back into schools as the university embarked on university-school partnership work focused on reforming specific partner schools. The transition made completing a dissertation "on the side" daunting, and indeed it has taken a longer time than it would have in a full time doctoral program. However, the lessons that I have learned through both working in schools on implementation of programs and policy related to reforming science teaching combined with the process of deeply studying teacher leadership for science education reform has been invaluable and I believe it could not have happened with either experience independently.

As I consider my career pathway, I recognize that in order for me to feel like a leader in science education, I must keep one foot in schools and one foot in the university. I would like to continue to build knowledge at the university-level that brings teachers voices to the forefront and informs policy such that I can inform the conversation about the structure of K-12 schools and higher education. I hope that this dissertation can be catalytic for changing the conversation about what it means to be a science teacher leader and inform how specific positions are structured such that our best science teachers can stay in the classroom while simultaneously informing science teacher education and science education policy.

Changes to university science education. I suggest that in addition to considering new roles for K-12 teachers, we should consider a different conception of university teacher education programs. This restructuring would focus on closing the gap between research and practice. Possible changes that could be made include:

(1) Increased focus on part-time doctoral programs for K-12 teachers
(2) Experiential coursework for full-time doctoral programs within K-12 settings
(3) Joint K-12 and university teaching appointments
(4) Required fieldwork for university faculty within K-12 schools
(5) Sabbaticals for K-12 teachers to teach at the university and for university faculty to teach at the K-12 level

I suggest that departments of education at universities could be restructured in these ways to better support hybrid roles and create better-informed teachers at all levels working together to implement and sustain science education reform

Directions for Further Research

Further research is needed on professional development programs that bring administrators and teachers together in service of pedagogic change and improved student learning. In addition, research on distributed leadership models in schools can better inform us about school-based models that support science teacher leadership. Further research to support ways to develop science teacher leader, specifically, rather than teacher leader, is also needed. Also, case studies of administrators and teachers who participated in PD together could add to the findings in this study. In addition, it would add value to more deeply explore the influence of science teachers who become administrators on science teacher retention and implementation of reformed science teaching. Finally, it is always important to consider how one might connect leadership practice to student learning outcomes.

Limitations of Study

This research was limited to a specific group of teachers and administrators, as well as specific data collected as part of the MSP program evaluations. The participants in this study were limited to those that were enrolled in the MSP programs. This limits the study participants to a particular type of science teacher—one who would apply and be admitted to a rigorous program at a prestigious university—and their administrators. Teachers were selected because they were already identified as leaders. While this is a limitation it also served to narrow the scope of the work by considering how this unique group of teachers defined leadership and consider the roles that they played.

In addition, the data was another limitation. Because the two MSP programs were developed independently, data sources, such as surveys, interviews, essays, and e-portfolios, were not available for science teachers across the MSP programs. Access to the limited data shaped the research questions by focusing them in on questions that could be answered with the data available. In the end, this strengthened the dissertation by providing focus to the work and leaving other questions that came up to be topics for further research. Furthermore, the different data sources available within each MSP program were limited by how they were presented to the participants. For example, the surveys, leadership essays, and e-portfolio rubrics gave prompts to teachers that may have encouraged a certain type of response. This was important because it provided insight into how structures of the MSP program influenced teacher leadership and how the teachers interpreted questions about science leadership related to their own personal definitions of the term.

Conclusion

The questions in this study provide important insights into the challenges faced by administrators and science teacher leaders as they engage with efforts for transforming science teaching and learning. In addition, these questions provide information about how a professional development program for administrators and teachers can contribute to the ways in which administrators and teachers support pedagogic change in the sciences. This work has contributed to the field because it goes beyond general teacher leadership (York-Barr & Duke, 2004) to focus on content-specific leadership in the sciences and explores the intersections of administrators, teachers, school context and professional development experiences for realizing science education reform. The current body of knowledge tells us that the presence and nature of leadership at multiple levels has a significant impact on the effectiveness of schools in educating students. This dissertation adds to this by focusing specifically on content-specific leadership in science and providing information about how a professional development program for teachers and administrators influences leadership practice. In addition, I provide details about the persistent challenges science teachers and administrators face as they attempt to enact reformed science leadership practice in order to transform science teaching and learning.

In this dissertation, my conclusions encourage reimagined roles for K-12 teachers and administrators that will help us meet the demands of science teaching and learning encouraged by reform documents. In addition, the findings suggest that thoughtful design of professional development programs can develop transformational teacher leaders and administrators who are confident pedagogic leaders. I hope that the findings in this study encourage administrators to seek the understanding needed to enact credible knowledge of science teaching and learning in order to truly support science teachers as they implement reformed science teaching. Finally, as an individual who left the classroom, I hope that science teachers will advocate for the creation of roles that keep them in the classroom while also allowing them to hold legitimate leadership roles. As I continue to work in my role at a university, I am constantly reminded, in both literature (e.g., Darling-Hammond, 2000; Johnson et al., 2007; Wright, Horn, & Sanders, 1997) and practice, of the importance of the teacher in the classroom for influencing student success. I only hope that this dissertation can ignite conversation that leads to (1) new models of science teacher education that engage administrators and support multiple pathways of science leadership and (2) innovative designs of K-12 schools that provide opportunities for our best science teachers to be BOTH excellent classroom teachers and legitimate leaders for reformed science education.

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