The continuum of secondary science teacher preparation

Knowledge, questions, and research recommendations

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The mission of the Knowles Science Teaching Foundation (KSTF), to increase the quantity of high quality high school science and mathematics teachers in United States High Schools, calls for a deeper understanding of what it takes to prepare and support successful teachers. On September 21, 2006, KSTF convened a group of 41 individuals with a broad range of perspectives and expertise to address three essential questions with regard to secondary science teacher preparation: What do we know, what do we need to find out, and what research will help us fill in the gaps? Participants were intentionally selected from a diverse cross section of the education community and included teachers, educational researchers, teacher educators, policy specialists and scientists. The 41 participants formed 12 working groups and spent two and a half days addressing the following aspects of teacher preparation:

- recruitment and retention;
- models of secondary science teacher preparation;
- pedagogic preparation including field-based experiences, methods courses, and preparing teachers for diverse populations;
- content preparation in biology, chemistry, Earth science, and physics as well as the nature of science in general;
- induction;
- mentoring.

Each working group was tasked with synthesizing their discussions and conclusions for the entire group of conference participants and in a written document. This volume represents the final outcome of that conference; 12 chapters that reflect the work of 41 dedicated scholars and practitioners who share a deep commitment to the pursuit of excellence in the preparation of secondary science teachers.
The Continuum of Secondary Science Teacher Preparation
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Knowledge, Questions, and Research Recommendations

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In 1983, the National Commission on Excellence in Education released *A Nation at Risk*, stating that “the educational foundations of our society are presently being eroded by a rising tide of mediocrity that threatens our very future as a Nation and a people.” More than twenty years later, *Rising Above the Gathering Storm* (Committee on Prospering in the Global Economy of the 21st Century, 2007) declared, “America today faces a serious and intensifying challenge with regard to its future competitiveness and standard of living. Further, we appear to be on a losing path.” International studies of student performance (i.e., Programme for International Student Assessment; Organization for Economic Co-Operation and Development, 2004; Stigler & Heibert, 1999) have consistently shown that students in the United States do poorly compared to students in other developed nations in both science and mathematics, particularly in applying knowledge to novel problems. Clearly, the United States faces a crisis with regards to science and mathematics education. This crisis will likely have a profound and possibly irreversible impact on the wellbeing of the nation if deep and sustained changes to the existing educational system cannot be enacted.

In order to ensure that Americans continue to share in the prosperity and security that science and technology are bringing to the rest of the world, The National Academies in *Rising Above the Gathering Storm* recommended recruiting 10,000 new mathematics and science teachers each year, each of whom should have a degree in mathematics or science and a teaching credential. It is clear, though, that developing the kind of expertise in teaching that leads to sustained and meaningful student learning takes time. In the United States almost half of all teachers leave the teaching profession entirely within the first five years of their careers (Ingersoll, 2003) and teachers with an undergraduate degree in science or mathematics are almost twice as likely to leave the profession as teachers with any other undergraduate degree (Borman & Dowling, 2008). Hence, recruiting top candidates into the teaching profession will hardly be sufficient to reverse the trend toward mediocrity in mathematics and science education if such recruits leave the profession within two to three years.

Beyond recruiting and retaining qualified individuals in K-12 mathematics and science education, the question of how to best prepare outstanding teachers remains highly contentious (Darling-Hammond, Barnett, & Thoreson, 2001; Levine, 2006). Reports claiming that university-based credentialing programs are failing to prepare teachers adequately are being used to justify placing individuals into classrooms, often in high-needs schools, with little or no preparation at all. Yet, researchers have found that teachers without a credential are more than two and a half times as likely
to leave the profession than are teachers with a credential (Borman & Dowling, 2008) and that teachers with a credential or similar preparation in education are more successful at producing student achievement (Darling-Hammond et al., 2001; Darling-Hammond, Holtzman, Gatlin, & Heilig, 2005).

It is within this complex context of science and mathematics education that Harry and Janet Knowles established the Janet H. and C. Harry Knowles Foundation (aka the Knowles Science Teaching Foundation and KSTF) in 1999 in recognition of the importance of high quality science and mathematics instruction to the well-being and future of our country, as well as in appreciation of the many dedicated science and mathematics teachers who helped shape their lives. The work of KSTF is rooted in the knowledge that teaching is a critically important, complex, intellectually challenging profession that demands the best efforts of our nation’s finest and that learning to teach requires time, sustained effort, and ongoing support and development throughout a teacher’s career.

The first executive director of KSTF, Dr. Angelo Collins, was hired in 2000 and spent a full year travelling the United States to speak with educational leaders, researchers, and others who work in science and mathematics education. She gathered extensive data about how to best invest in high school science and mathematics teachers given the prospective size of the Foundation’s endowment. During that time she heard Harry and Janet emphasize their commitment to supporting individuals rather than institutions and their commitment to people in the early stages of their careers. In 2001, Dr. Collins proposed to the Board of Trustees that the bulk of the Foundation’s operating budget be used to fund fellowships for beginning high school science and mathematics teachers. The KSTF Science Teaching Fellowship Program began in 2002 when fellowships were offered to four individuals planning to teach high school physics. KSTF added a Mathematics Teaching Fellowship in 2005 and a Biology Teaching Fellowship in 2008. By 2013 the Teaching Fellowship program will reach a steady-state condition of approximately 180 active fellows – 60 in each of the three disciplinary strands – with the number of alumni increasing each year.

Because the practice of teaching evolves over time, the study of teaching and scholarly discourse by teachers, researchers and the broader education community is a critical component of KSTF’s mission. In its early years, KSTF funded small research grants for work focused on beginning high school mathematics and science teachers. In 2005, the grants program was replaced with the KSTF Research Fellows program that provides 2-year fellowships for early career scholars from a variety of disciplinary backgrounds, whose work contributes to scholarship related to issues in the recruitment, preparation, induction, mentoring, and retention of science and mathematics teachers in United States high schools.

The third of KSTF’s three programs, a biennial conference series, was developed with intent of providing an opportunity for scholars in education, science, and mathematics, experienced teachers, and KSTF Research and Teaching Fellows to meet and discuss important topics in science and mathematics education. The inaugural conference in the KSTF Conference Series was held with support of the Johnson Foundation on September 19-2, 2006, at the Wingspread Conference
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Facility in Racine, Wisconsin. It focused on essential research for the preparation of secondary science teachers. The second conference on essential research for the preparation of mathematics teachers was held in May 2008.

KSTF’s mission of supporting outstanding beginning high school science and mathematics teachers calls for a deeper understanding of what it means and what it takes to learn to teach. This need drove KSTF to focus its first conferences on refining the questions and findings of existing syntheses of teacher education research to the specific case of secondary science and mathematics teacher preparation, where “preparation” is viewed as a continuum beginning when an individual initially decides to pursue high school science or mathematics teaching and continuing through the first few years of teaching. Because of the differences, some subtle and some profound, between mathematics and science teachers at the level of preparation, policy, and practice, KSTF decided to hold separate conferences focused on science then mathematics.

For the first conference on science teacher preparation, KSTF established four overarching goals.

– Using existing syntheses of teacher preparation research (Cochran-Smith & Zeichner, 2005; Darling-Hammond & Bransford, 2005; Wilson, Floden, & Ferrini-Mundy, 2001), as well as additional appropriate research literature, map out what the broad community of individuals, institutions, and programs involved in science teacher preparation know, how we know it, and what assumptions we hold or commitments we share about each facet of the secondary science teacher preparation continuum.

– Identify crucial gaps in our knowledge, pose important questions that the science teacher preparation community feels need to be answered, and justify why such knowledge is crucial.

– Propose specific research projects, both large and small, that will fill the knowledge gaps and answer the questions posed.

– Produce a written document that could serve as a resource to the broader community involved in secondary science teacher preparation, including researchers, practitioners, and policy makers.

On September 19, 2006, a group of 41 individuals with a broad range of perspectives and expertise on science teacher preparation convened at the Wingspread facility to address the goals established by KSTF. The conference participants were divided into 12 working groups and spent two and a half days addressing the core questions of what we know, what we need to find out and what research will help us fill in the gaps. Each working group addressed one of the following aspects of secondary science teacher preparation: recruitment and retention; models of secondary science teacher preparation; pedagogic preparation including field-based experiences, courses on methods of instruction, and preparation for diverse populations; content preparation in biology, chemistry, Earth science, and physics; learning and teaching about the nature of science; induction and mentoring. Each working group was tasked with synthesizing their discussions and conclusions for the entire group of conference participants and in a written document. This volume represents the final outcome of that conference; the work of 37 dedicated scholars
The chapters in this volume can be loosely grouped into four themes. The first two chapters focus on systemic issues of recruitment and retention and a discussion of various models used to prepare new science teachers. The next four chapters focus on specific components common to most university-based science teacher preparation programs: science methods courses, field-based or student teaching experiences, and preparing teachers for diversity. Because KSTF views teacher preparation as extending beyond what happens in a formal preparation program, we included a focus on how teachers learn the science content that they subsequently teach and how they continue to learn to teach once they are in the classroom. Thus, four chapters in this volume address specific issues of content preparation in the four disciplines most commonly taught at the secondary level and one chapter addresses issues of learning about and learning to teach the nature of science. The final two chapters address issues of science teacher learning within induction programs and the impact of mentoring on beginning science teachers.

**Systemic Issues**

This volume opens with a chapter by Coble, Smith, and Berry addressing key issues in the recruitment and retention of science teachers. The authors argue that although the “crisis” in science teaching and the shortage in science teachers is difficult to validate with empirical data, meta-analyses indicate that a persistent but fluctuating shortage of science teachers exists in the United States and that the problem appears to be one of retention rather than production. Furthermore, the authors point out, although participation in an induction program tends to improve teacher retention, induction models in the United States tend to be weak compared with countries whose students outperform U.S. students in mathematics and science. In order to develop a deeper understanding of science teacher recruitment and retention, the authors suggest that we need to know more about the specific conditions under which qualified and effective science teachers are attracted and retained in high-needs schools and the backgrounds of those teachers. The authors also argue for more research explicating how changes in state policies, particularly those on accountability and teacher certification, affect the shortage of science teachers.

Chapter 2 delineates what is known about various models of science teacher preparation and their effectiveness. Much like teacher preparation in other subject areas, a wide variety of program structures exist for preparing science teachers; science teacher preparation is not a monolithic entity. The authors, Fraser-Abder, Abell, and Trumbull, point out that research on teacher education plays a smaller role in the design of teacher preparation programs than do political and societal factors. They call for a specific taxonomy of science teacher preparation programs that would include elements characterizing existing programs and a means of
classifying new programs. Once a clear taxonomy is developed, the authors propose that research must be conducted to determine which models of science teacher preparation are more effective in terms of both teacher and student learning on a number of different dimensions. Furthermore, they argue that research is needed that will move the field toward a deeper understanding of how policy affects science teacher education practice and how research can affect policy.

Common Elements of Science Teacher Preparation Programs

Within the variety of models of science teacher preparation programs discussed in chapter 2, prospective teachers experience myriad ways and means of learning to teach science. Perhaps the most common element of all preparation programs is a course (or courses) focused on providing instructional principles and assessment strategies, which despite the variation in course names across institutions, can be classified as science teaching methods. In the chapter 3, the authors, Van Zee, Long, and Windschitl, unpack key issues related to methods courses, including the principles behind and practice of instruction, what prospective teachers learn in the courses and links between methods courses, and other elements of the teacher preparation program. The authors argue that methods courses must undergo a shift in focus from what teachers do to how students think and learn. Research, of course, is needed to help methods instructors make this shift. Additionally, the authors call for more self-study of methods instructor’s own practice, as well as systems approaches that investigate how learning methods courses are connected to other elements of teacher preparation programs, teacher practice, and eventually, student learning.

In addition to teaching methods courses, most science teacher preparation programs include one or more field experiences that may include observations, student-teaching placements, and even internships in which the novice teachers function as the teacher of record. Oliver, the author of the fourth chapter discusses the kinds of knowledge a prospective teacher might be expected to possess at the end of an “ideal” field experience and what might comprise such an ideal field experience. A review of existing research on field placements suggests that more needs to be known about the variety in the content, context, and duration of field experiences in various models of science teacher preparation and what works in terms of successful teaching.

Currently, teacher preparation in the United States means preparing an increasingly white, monocultural, and monolingual teacher workforce to work with an increasingly linguistically, racially, and culturally diverse population of students. Preparing science teachers comes with the additional responsibility of knowing that the number of science teachers without a credential in the largest cities and rural districts is increasing, particularly in high poverty schools. In chapter 5, Calabrese Barton, Rubel, Furman, and Lopez-Freeman identify three areas of learning to teach for diversity: 1) a teaching identity grounded in desire to act for change; 2) being able to identify relationship between access to science and equity in society, and 3) possessing pedagogical and curricular strategies to bridge the knowledge and experience of youth with school science. Within those three areas, they recommend
specific studies that need to be conducted in order to gain a deeper understanding of teachers’ trajectories and contexts in learning to teach for diversity. Additionally, the authors recommend more detailed syntheses of existing research, including reviews of court cases, legislation, and other activities that impact learning to teach science to all students.

Content Preparation for Science Teachers

KSTF and the authors of this volume are committed to the view that teacher preparation begins with the teacher’s own learning of disciplinary science knowledge. Thus, chapters 6 through 10 address issues of content knowledge preparation for science teachers in the four disciplines most commonly taught at the high school level as well as the learning and teaching about the nature of science more generally. Although secondary science teacher preparation programs rarely focus specifically on a discipline, the conceptual structures and scientific practices of the various disciplines are different enough to warrant separate consideration of what it is that teachers need to know and be able to do within the disciplines they teach.

Biology is the most commonly taught science subject at the secondary level and the scientific discipline in which most secondary science teachers have undergraduate level preparation. Chapter 6 begins with a discussion of the intended outcomes of a content preparation program for biology teachers, including an understanding of the discipline (concepts and tools of inquiry), pedagogical content knowledge, and the use of data to make decisions that increase students’ opportunities to learn. Carlson, Waterman, and McNicholas review research on the effects of biology content preparation on student achievement and argue that further research is needed to explicate the knowledge and skills teachers need to support student inquiry, strategies to develop pedagogical content knowledge in biology, the effects of various elements of undergraduate biology education on teacher knowledge, and a more nuanced understanding of the relationship between teachers’ disciplinary understanding and student achievement.

In chapter 7, Talanquer, Scantlebury, and Dukerich examine four dimensions of chemistry subject matter knowledge for teaching: content knowledge, knowledge about the nature of the discipline, beliefs about the subject matter, and knowledge of content representations. They review existing literature in each of those areas, some of which specific to chemistry and some of which has findings that may be extrapolated to chemistry teachers. One of the key recommendations made by the authors is that a clearer understanding is needed of the forms of teachers’ subject matter knowledge most effective in promoting student understanding in a wide variety of classroom settings. They also argue for studies that unpack the effects of teachers’ chemistry subject matter knowledge on classroom practice in the context of various curricula. Furthermore, they argue that the generic nature of science studies examining teachers’ understanding of the goals and practices of science need to be refined to capture the unique aspects of chemistry as a discipline. These
unique aspects include the fact that chemists are the creators of their own objects of study and the existence of qualitative models in chemistry.

Teachers of Earth and space sciences face an exceptional challenge in that their subject requires knowledge of physics, chemistry, and biology, combined with unique Earth science research methods to investigate Earth events and phenomena. This unique challenge, thus, has implications for the preparation of prospective Earth science teachers. In chapter 8, Pyle and Brunkhorst discuss a basic framework for geosciences that distinguishes the geosciences from other sciences and the knowledge, skills, and dispositions core to teaching and learning the geosciences. They point out that few research-based descriptions exist of necessary core concepts in the geosciences and that geosciences have relatively little connection with science education, as compared to other science disciplines. Further, they argue for more research on identifying geosciences pedagogical content knowledge for Earth science teachers and ways to effectively develop Earth systems understanding both in schools and in the broader public.

Physics, perhaps more than any other science discipline, has a solid research base of adult learning (including prospective and practicing teachers) on which to draw. The authors of chapter 9, Gillespie and Elby, draw on this research and review the current state of physics teaching at the secondary level in order to set the stage for a discussion of the disciplinary knowledge needed by physics teachers. The authors argue that despite the existence of a broad base of physics education research on student misconceptions and effective instructional practices, further research is needed to determine the impact of physics teachers’ conceptual understanding on student achievement. They further recommend research to bridge existing work in undergraduate students’ epistemology of physics with physics teachers’ content knowledge and epistemology, and ultimately, their own students’ achievement. Finally, they make the case that education and physics education researchers need to collaborate to map out the domain of physics content knowledge for teaching and begin investigating best practices for supporting teachers’ learning of such content knowledge.

Secondary science teacher preparation programs often provide prospective teachers some exposure to new science content, but the general working assumption of most teacher preparation programs is that prospective teachers enter a credentialing program with sufficient content knowledge to teach their intended subjects. In chapter 10 Lederman argues that in the arena of science teacher preparation, knowledge about the nature of science should be treated as equivalent to the traditional concepts of scientific disciplines. Despite this need, articulated in science education standards and the author’s own research, teachers of science at all grade levels lack an adequate understanding of and ability to teach the nature of science. The author makes a case for additional research to further unpack how teachers’ understandings of the nature of science develop and is related to their content knowledge and how knowledge of the nature of science impacts their instructional practice.
While chapters 6 through 10 focus on aspects of learning to teach science that occur often before a formal teacher preparation program begins, the final two chapters of this volume focus on aspects of teacher learning that occur after a teacher is in the classroom on a full-time basis. Chapter 11 focuses specifically on science-specific induction programs and research on the efficacy of such programs. In the last decade, approximately a dozen science-specific mentoring programs have been implemented that, to varying degrees, include elements such as subject-matched mentoring, science-specific professional development courses, and minicourses for specific science topics and teaching strategies. Britton argues for more research documenting the science-specific needs of beginning science teachers and the impact of science-specific induction on teaching and student learning, but also for research on the optimum balance of addressing science-specific and general teaching needs in induction.

One of the most common aspects, and sometime the only aspect, of teacher induction is some form of mentoring. Chapter 12 examines the role of mentoring in support of science teaching, as both a means of individual development and of achieving institutional goals. Koballa and Bradbury cite research showing same-subject mentoring to have a positive impact on teacher retention, but also finding that science teachers rarely have a mentor who also teaches science, much less one who teaches the same science subjects. Additional research on mentoring includes work on understanding mentor roles and practices, professional development for mentors, and the addressing science-specific needs of new teachers in the context of standards-based reform. The authors argue for more research that can shed light on mentoring as a way of guiding science teacher growth toward standards-based practice and the effects of science teacher mentoring on student achievement in science.

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REFERENCES


CHARLES R. COBLE, THOMAS M. SMITH, AND BARNETT BERRY

1. THE RECRUITMENT AND RETENTION OF SCIENCE TEACHERS

Most academics, journalists, and business and political leaders believe, with good reason, that in today’s global, high-technology economy, America’s well-being hinges on the competitiveness of its citizens and the scientific and technical advances they create. Indeed, the recent report, *Rising Above the Gathering Storm* (Committee on Prospering in the Global Economy of the 21st Century, 2007), issued a stern warning: “Without high-quality, knowledge-intensive jobs and the innovative enterprises that lead to discovery and new technology, our economy will suffer and our people will face a lower standard of living.” The 2000 report of the National Commission on Mathematics and Science Teaching for the 21st Century concluded similarly and explicitly linked our nation’s lack of technical competency with the public schools and their failure to “capture the interest of our youth for scientific and mathematical ideas” (p. 4). The Commission, chaired by Senator John Glenn, noted that the global marketplace demands “widespread mathematics- and science-related knowledge and abilities” among American workers and that these fields are “primary sources of lifelong learning and the progress of our civilization” (p. 7).

The findings of these high-profile reports were echoed in Thomas Friedman’s (2005) provocative book, *The World is Flat*, in which he described how cheap, ubiquitous telecommunications have transformed our conceptions of global economic competition and how nations with the “best education system” and the “most educated work force” (as well as those with the most investor-friendly laws and the best environment) will garner the most profit and opportunities.1 Approximately 50 years after the Soviet Union’s launch of Sputnik, policymakers are once again paying close attention to how American students are performing in science and who is teaching them.

Researchers continue to document the lack of international competitiveness of America’s public school students. For example, on the 2003 Program for International Student Assessment (PISA; Organisation for Economic Co-Operation and Development, 2004), the U.S. ranked 19th out of 40 countries in reading, 20th in science, and 28th in mathematics (on a par with Latvia), outperformed by nations like Finland, Sweden, Canada, Hong Kong, South Korea, the Netherlands, Japan, and Singapore. In the mid-1990s U.S. students fared no better on the Third International Mathematics and Science Study (TIMSS). Students from 20 nations were tested in advanced mathematics and physics. In physics all of them, except one, scored better than the United States (and all scored better in advanced math). America’s poor performance on both the PISA and TIMSS poses a special

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challenge—given that these international examinations assess students’ ability to apply knowledge to complex problems in new situations. Researchers have shown that the poor performance of American students has less to do with the qualifications of science teachers and more to do with the ways they teach (Stigler & Hiebert, 1999).

Political and business leaders often blame the lackluster performance of U.S. students on international assessments on the critical shortage of qualified teachers in science, mathematics, and technology. Several years ago the National Research Council (2002) estimated that over the next decade approximately 2 million teaching positions would need to be filled and nearly 200,000 of those would be secondary mathematics and science teaching positions. Researchers have long documented that, compared to other subjects, science classes are more likely to be taught by unqualified and underqualified teachers—and administrators consistently rate science teachers as some of the most difficult to recruit and retain.

The problem is not only who is teaching and who remains in the profession, but how they are prepared and how they teach science. Researchers have difficulty in determining what constitutes teacher effectiveness. However, the most consistent and most powerful predictors of higher student achievement in science have been whether or not teachers are fully certified and have earned a college major in the field they teach (Monk, 1994). Students with teachers who were experienced, prepared, and fully credentialed (i.e., not entering teaching through one of a state’s several alternative route programs) were more likely to produce higher student achievement gains on end-of-course tests in subjects like biology. Clotfelter, Ladd, and Vigdor (2007) found that students “exposed” to a teacher

with very weak credentials (one with no experience, low licensure test scores, a lateral entry license, certified but not in subject specific or related field, not Board Certified, no graduate degree and from an uncompetitive college)… would be expected to achieve close to .30 standard deviations lower than if they had a teacher with the strong set of credentials. (p. 29)

According to the latest data from the School and Staffing Survey (SASS; Ingersoll & Perda, 2006), there are about 223,000 science teachers teaching in America’s schools—of which about 15%, or 35,000, were new hires (for the 1999–2000 school year). Approximately 53% of these science teachers moved from another school, while 32% were new to teaching and 15% returned to teaching from the reserve pool. At the same time almost 40,000 science teachers left their classrooms, with 46% of them moving to other schools and 54% leaving the profession. During the same year only 12,100 science teachers were produced by our nation’s colleges and universities. Most of these newly minted science teachers were non-education majors, who enter teaching with limited preparation.

These data begin to surface a more complex picture of the nature of science teacher shortages and the complexities of addressing them. These matters are made more difficult by the lack of reliable and timely data to accurately define the extent of the shortages and the most viable ways to recruit and retain the kinds of science teachers needed for America’s schools.
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A set of questions frames efforts to better understand how to recruit and retain effective science teachers for our nation’s schools. These include

1. How are prospective secondary science teachers prepared and certified before they enter teaching (either through traditional or alternative routes)?
2. How many secondary science teachers in specific science disciplines are produced and where do they teach (if they do)?
3. What is the extent of out-of-field science teaching of science teachers, and what accounts for its prevalence?
4. How well prepared are elementary teachers who teach science?
5. What factors most influence science teachers to stay in teaching—and what prompts them to leave, if they do?
6. What incentives are needed to recruit nontraditional candidates to science teaching—and what kind of preparation do they need before they begin to teach?
7. What kinds of subject-specific induction and professional development are needed to improve the effectiveness of science teachers—especially for 21st-century teaching and learning?
8. Who are the most effective providers of science and mathematics teachers?

Unfortunately, due to the lack of sound data systems and well-developed research agendas we will not be able address all of these questions in our review. For example, well-designed research studies documenting the factors affecting a person’s decision to become a science teacher are thin. Although many program descriptions claim effectiveness in recruiting prospective teachers into science teaching, there is little underlying research about the key variables related to their reported effectiveness. A large and growing research base on factors and programs affecting teacher retention is available, but the literature devoted specifically to science teachers is sparse.

Even lacking firm numbers, since the 1980s a number of reports from prominent national education organizations have warned of a significant shortage of elementary and secondary school teachers, particularly in the areas of science and mathematics (National Commission on Excellence in Education, 1983; National Commission on Mathematics and Science Teaching for the 21st Century, 2000). Recent studies have indicated that teacher shortages are concentrated predominantly in the areas of special education, mathematics, and science—notably the physical sciences (Murnane, Singer, Kemple, & Olsen, 1991). The primary policy and program response to the warnings—and the realities—of teacher shortages has been to focus on recruiting more people into teaching. Over time, a growing recognition has emerged that retention of teachers is equally if not more important if our nation is to build and maintain a high-quality teaching force, especially in the sciences (Ingersoll, 2003a).

The National Commission on Teaching and America’s Future (2003) report, No Dream Denied, persuasively argued that “the conventional wisdom is wrong” (p. 21) and that “teacher supply is generally adequate to meet the demand” (p. 23; italics added for emphasis). Despite this assessment, there do appear to be shortages in some science and mathematics disciplines and in special education. This paper
focuses on the research and findings related to recruitment and retention of science teachers. As stated earlier, available research from which firm conclusions can be made is scant.

[Note: A review of the larger body of research associated with the topic of this paper is captured in the comprehensive 2005 Education Commission of the States publication by Michael Allen, *Eight Questions on Teacher Recruitment and Retention: What Does the Research Say?* Also worth considering is Berry’s (2007) synthesis paper, “Recruiting and Retaining Quality Teachers for High-Needs Schools,” commissioned by the National Education Association. The latter proposes solutions – a number of them generated by the teachers policymakers seek to recruit into high needs schools and subjects.]

**IS THERE EVIDENCE OF A SCIENCE TEACHER SHORTAGE?**

Numerous reports and studies talk about the “crisis” in science (and mathematics) teaching, citing as a key issue the “shortage” of teachers in these disciplines. However, data to confirm these assertions are hard to validate, so the claims of overall shortages of science and mathematics teachers have taken a life of their own. There may well be a shortage of science teachers, but the nature of the shortage appears to be more complex and perhaps even worse than described. This is especially true if one considers the definition of science teachers included in the report by the Glenn Commission (U.S. Department of Education, 2000):

> All teachers, grades K–12, who provide instruction in mathematics or science for some part of the school day are math or science teachers. The elementary school generalist, the high school teacher specializing in physics, as well as the drama teacher who may be assigned to a single geometry class, are all persons whose teaching quality is of interest – and of consequence – to the nation. (p. 18)

This definition encompasses several issues related to fully understanding the nature of teacher shortages in science teaching: (a) the production of secondary science teachers in specific science disciplines; (b) the preparedness of elementary teachers to teach science; (c) out-of-field teaching of science teachers; and (d) the rigor of science preparation for all who teach science. This definition does not address issues associated with the distribution of highly qualified K-12 teachers of science.

In a study on the supply and possible shortages of secondary science teachers throughout the United States, Hudson (1996) conducted a survey of the science consultants to the state boards of education in the 50 states and the District of Columbia. The response rate was 96%. Using the information gleaned from the survey and by analyzing 45 previous studies of science teacher supply, Hudson found convincing evidence to support the hypothesis that there is a persistent but fluctuating long-term shortage of science teachers. Hudson cited survey reports by the National Education Association, the Association of School, College and
University Staffing, and the National Center for Education Information over several decades to support the claim that science teacher shortages are persistent.

The reported shortage of science teachers is not a recent phenomenon. For example, Hudson’s comparison of 1992 and 1982 survey results showed that for the entire sample there was a net surplus (31%) of biology teachers; even so, approximately 10% of states reported a shortage of biology teachers. For the entire sample the largest science teacher shortage was in physics, with a net shortage of 61%, and no state reported a surplus of physics teachers. The net shortage of chemistry teachers for all states surveyed was 33%, and for Earth science teachers the net shortage was 31%. Although the shortages were less severe than in 1984, states were still reporting shortages 10 years later. The actual numbers in the early 21st century are not definitively known, but the general perception is that the United States is again experiencing an increased shortage of certified science teachers (Hudson, 1996).

The American Association for Employment in Education has conducted an annual survey of higher education institutions preparing teachers for almost three decades. The supply-demand reports generated by these surveys of deans of education and career services officers on campuses have tracked the realities in K-12 schools. Special education, mathematics, and physics were fields perceived to have considerable shortages. The survey results indicate the teacher shortage overall peaked in 2001 and has declined until 2004, the latest year reported (Bradley, Sampson, Ma, & Cunningham, 2006).

Concerns about recruiting and retaining science teachers often focus on secondary science teachers, but by far the largest numbers of science teachers are at the elementary school level. The preparation of elementary teachers to teach science – and their self-reported feelings of lack of preparedness to do so – along with the amount of time they devote to science teaching, are long-recognized concerns (Coble & Koballa, 1996). Recent reports document that elementary teachers do not feel qualified to teach science (Hudson, McMahon, & Overstreet, 2000, as reported in National Science Board, 2006). According to a national survey of elementary teachers, 76% reported feeling very qualified to teach reading/language arts, almost 60% reported feeling very well qualified to teach mathematics, 52% reported feeling very well qualified to teach social studies, but only 30% felt very well qualified to teach life science (Smith, Banilower, McMahon, & Weiss, 2002).

Although numbers are not easily obtainable about the precise nature of the shortage of science teachers or about effective actions to strengthen elementary teachers’ sense of preparedness to teach science, there is little debate about the demographics of the general teaching force – that it does not mirror the demographics of the student population in either race or gender. Students are increasingly persons of color, but the general teaching force has become increasingly white (86%) and female (79%; Allen, 2005). Science teachers likely are reflective of the general teaching force in that regard. Although there is evidence that the percent of males teaching science is higher than the general teaching force (Henke et al., 1997), it is reasonable to suggest that males entered teaching in higher numbers during a time when military deferments were offered to science teachers. Feistritzer
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(2005) reported that a high percentage of the male teaching force in science is currently at retirement age. With an all-voluntary military and no incentive of a military deferment, it is uncertain whether males – white, black, or otherwise – will continue to enter science teaching.

The National Commission on Teaching for America’s Future (NCTAF, 2003) takes issue with the general notion of teacher shortages, mainly the argument that we are not training an adequate number of science teachers:

It has become conventional wisdom that the ability to improve schools and instruction is limited by a national teacher shortage. … But, the conventional wisdom is wrong. The real school staffing problem is teacher retention … turnover that is only aggravated by hiring unqualified or underprepared individuals to replace those who leave. (p. 8)

Although not specifically addressing science teachers, the NCTAF offered compelling evidence to support its claim that shortages have more to do with turnover than an inadequate supply of new science teachers, some of which is presented in the following discussion on retention.

RESEARCH ON THE RETENTION OF TEACHERS, IN GENERAL, AND SCIENCE TEACHERS, SPECIFICALLY

A 2000 survey by the National Science Teachers Association revealed that over 30% of science teachers in their beginning years are considering leaving the profession. Attrition of both new and experienced teachers is a great challenge for schools, school administrators, and policymakers throughout the United States, particularly in large urban districts and in some rural districts – particularly in science and mathematics. Of the relatively large amount of empirical literature that investigates why teachers quit and how they might be better induced to stay in the profession, little specifically addresses science teachers.

Byrd (2007) revealed that former science teachers would most likely be attracted back into the profession if salaries were increased, but also if school leaders were more effective and supportive and strong school-community partnerships were in place. The study, drawing on a sample of former science (and mathematics) teachers in South Carolina, elicited their ratings of the working conditions in their former schools and analyzed the probabilities and possibilities of them returning to the profession.

WHO LEAVES AND WHY?

Johnson, Berg and Donaldson in their 2005 report, Who Stays in Teaching and Why, recounted that in recent years 450,000 teachers – one sixth of the nation’s teaching force – exit the teaching force or switch schools each year. Nearly 40,000 of these are science teachers, with about 22,000 leaving the occupation and 18,000 moving to a different school. Although turnover rates for science teachers (17% in 2000–2001) are not so different from teachers in other fields (15.7%), principals
report greater difficulty hiring life and physical science teachers than English or social studies teachers, although hiring mathematics and special education teacher tended to be difficult in more schools.

Further, Ingersoll and Perda (2006) found that school poverty, school size, and the urbanicity of the school community were among the factors most predictive of teacher turnover in public schools. For example, while annual turnover rates in large, suburban, not-poor schools were 11%, the comparable figure for small, urban, poor schools was 26%. Further, there is evidence from Texas that “movers” show a strong flow of teachers from high poverty to low poverty schools, exacerbating gaps in teacher quality (Hanushek, Kain, & Rivkin, 2004).

Ingersoll and Perda (2006) also reported that among science teachers’ inadequate preparation time (69%) and lack of faculty influence and autonomy (62%) were the two most common sources of dissatisfaction among teachers who moved from or left their schools between 1999–2000 and 2000–2001. Other factors included class sizes that were “too large” (51%), insufficient computers and technology (49%), which could be a proxy for lab equipment, poor salaries and benefits (46%), and student behavior problems (46%).

TEACHER SALARIES

Higher salaries, overall, are generally seen as essential to recruiting high-achieving students into teaching. Ballou and Podgursky (1995), in analyzing data from teachers in the National Longitudinal Study of the High School Class of 1972, found that a 20% salary increase for all teachers would be associated with an increased ability to attract new teachers with higher test scores.

Low salary as an impediment to entering science teaching is a long-standing problem. Hounshell and Griffin (1989) surveyed 89 science education majors, and of the nearly 72% responding, 48% reported they were not teaching. Of those not teaching, 31% identified low salary as the main causal factor affecting their decision not to enter teaching.

Although the nationally representative SASS data reported by Ingersoll and Perda (2006) suggested that salaries are not the primary reason teachers turn over, low salary remains one of the perennial problems associated with teacher retention in the United States, and for science teachers the problem is more demonstrable. In a 2002 survey, teachers in California who were considering leaving the profession ranked “salary considerations” as the most important factor driving their decision (Tye & O’Brien, 2002).

Similarly, Gritz and Theobold (1996) found that compensation was the most important influence on the decision to remain in the profession for male teachers and experienced female teachers. According to Clewell and Forcier (2000), a large salary differential exists between science professionals and teachers. For example, of 1992–93 bachelor’s degree recipients who were employed full-time in 1997, the average annual salary of scientists/engineers was $39,000 compared with $25,500 for K-12 teachers (U.S. Department of Education, 2000).
Hanushek et al. (2004), analyzing Texas data, found that teacher mobility (transferring and leaving) was more strongly associated with the achievement and race of students in teachers’ schools than with salaries—estimating that salaries would need to be increased by 10–50% to offset the likelihood of teachers quitting in different types of schools.

TEACHER PREPARATION

How teachers are prepared appears to play an important but not well-understood role in teacher retention. In general, teachers who graduate from traditional university-based programs have lower attrition rates than teachers with other, nontraditional forms of preparation (Harris, Camp, & Adkison, 2008; Ingersoll & Smith, 2004; Smith, 2007). However, a large percentage of new teachers also report that their teacher preparation programs did not provide enough help for them to cope with their first-year experience, which intensified the need for proper mentoring, professional development, and administrative support in their working environment (Tapper, 1995). A study by Fisk, Prowda, and Glazerman (2004) on new teachers in Connecticut reported that those who were working in alternative licensure programs to correct “deficiencies in their certification” had nearly double the departure rates from teaching as their fully licensed counterparts. This was especially true for mathematics and science teachers, who left at double the rate of other alternatively certified teachers.

Johnson, Birkeland, and Peske (2005) pointed out that the teachers suffered from “serious shortcomings” in their alternative certification preparation – both during their truncated preservice training program and the mentoring that was offered to them by their district or the program itself. The researchers noted that these alternative certification teachers lamented,

the lack of training in how to teach their subject; mismatched student teaching placements with untrained mentors, inattention to the challenges of teaching students of a different race or background; the lack of assistance in finding a job; and inadequate follow-up support once they began teaching. (Executive Summary, p. vii)

The Harvard researchers noted ironically that “brief, inexpensive, convenient and practical training” (p. 6) were key to attracting midcareer professionals to teaching, but also were the root cause of the inadequate time spent learning how to teach and the insufficient resources available to deliver high quality preparation.

Humphrey and Wechsler (2005) found that most of the shortcut alternative certification programs investigated did not necessarily attract candidates from the high demand, private sector occupations—a finding that has flown in the face of conventional wisdom. The study, which examined seven well-recognized programs, revealed that this finding held for science teachers. The study also found that the prior teaching experiences of alternative certification candidates (which many of them had) influenced their sense of effectiveness in the classroom, a factor known to be related to student achievement.
The researchers also found a strong connection between the teachers’ educational backgrounds and their performance on measures of teaching knowledge in reading and mathematics and illuminated the central role of the school environment in the longevity of new teachers’ careers and the development of their teaching skills and knowledge. In addition, the study identified the importance of assessing teacher candidates’ skills throughout their preparation and initial teaching, and it emphasized the crucial role of effective mentoring and school placement.

Most of the research in this area has examined traditional teacher education and the kind of truncated alternative certification programs designed to fast-track the pedagogical training of teachers. Little attention has been paid to unique alternative nonprofits—like the Exploratorium—a hands-on science museum focusing on the kind of 21st-century content and pedagogical skills needed by tomorrow’s science teachers (Crutchfield & McLeod, 2007).

MENTORING AND INDUCTION OF NEW TEACHERS

Participation rates in induction programs by beginning teachers have risen dramatically over the past few decades. During the 1990s the increase was particularly dramatic, rising from about 4 in 10 beginning teachers in 1990–91, who reported they “participated in a formal teacher induction program, that is, a program to help beginning teachers by assigning them to master or mentor teachers,” to about 8 out of 10 in 1999–2000 (Smith & Ingersoll, 2004). In practice, these support systems can refer to a variety of different activities—workshops, collaboration, orientation seminars, and especially mentoring. It is probably safe to say that all districts and schools now provide at least some orientation for new and beginning teachers, such as introducing them to school and district personnel, resources, and procedures, but this level of orientation is inadequate to the needs, especially, of teachers new to the profession. The proportion of teachers receiving a high intensity induction program, in which new teachers meet frequently with a mentor in the same subject area, receive feedback on their teaching, and collaborate with other colleagues on instruction, is considerably smaller.

No universal definitions exist for “mentoring” and “induction,” but the objective of most induction activities for new teachers is to socialize them to their new roles in the occupation, to enhance their effectiveness, and to increase the likelihood that they will remain in the profession. But too few school districts provide the kind of support recognizing that the transition from college and student teaching or from a midcareer profession into the first year of teaching is a giant leap—and many beginning teachers simply do not make it. Ingersoll (2002) reported that 14% leave by the end of their first year, 24% by the end of the second year and 33% by the end of the third year of teaching.

A report released by the American Association of State Colleges and Universities (AASCU, 2006) found that 30 or more states have some form of mandated mentoring programs. However, only 16 states require and finance mentoring for all new teachers. Only five states provide a minimum of 2 or more years of state-financed mentoring, down from 8 in 2003. Reporting on in-depth data collected
by Education Week in 2003, AASCU indicated that nine states specified a minimum amount of time for mentors and new teachers to meet; eight required mentors and teachers to be matched by school, subject and/or grade; nine required mentors to be compensated for their work; and seven required release time for mentors.

The ability of states to mandate and regulate the effectiveness of induction programs is questionable. Smith (2007) found that though states mandating participation in induction programs tend to have more beginning teachers mentored, no guarantee exists that all teachers will be mentored. He also found state-level funding for these programs not to be associated with an increase in the likelihood of mentorship. Requiring that beginning teachers and their mentors be matched by subject, grade, or school does not appear to increase the likelihood of such a match, although states having this requirement do have mentorship programs that are more effective at reducing turnover.

The NCTAF (2003) has concluded that well-designed and effectively implemented mentoring for new teachers during their early years of teaching years can significantly reduce teacher shortage problems. Teachers who have no induction program are twice as likely to leave in the first three years of teaching. (p. 3)

In a report prepared for the Glenn Commission, Britton et al. (2000) reported that one-on-one mentoring is the most prevalent U.S. strategy for supporting new teachers, which is weak in comparison to the support provided to beginning teachers in many other countries – especially those outperforming the U.S. on international tests of science and mathematics. The authors concluded, after examining mentoring and induction in the U.S. and comparing practices in several foreign countries scoring well on international tests of science and mathematics, that

1. Effective mentoring practices can and should include (a) selecting mentors who meet the individual’s needs; (b) providing solid training for mentors; and (c) using multiple mentors for support. This helps increase the novice’s skill with general teaching abilities learned in teacher preparation programs, such as handling discipline problems, using effective questioning techniques and instructional planning.

2. Effective induction efforts go beyond a supportive role and are not limited to responding to teachers’ day-to-day crises and providing general teaching tips. Strong induction programs are 2 to 3 years in duration and go much deeper into subject-specific issues in curriculum and instructional practices, evaluating students’ learning, writing informative progress reports and communicating effectively with other professionals and with parents.

One science-specific mentoring program that includes many of these components is the Alternative Support for Induction Science Teachers (ASIST) program, designed by Julie Luft and colleagues (Luft & Patterson, 2002). The program has operated at two different universities, one for a 5-year period and another for 2 years. The primary goal of the program was to facilitate the building of teachers’ pedagogical content knowledge and to reinforce emerging beliefs about teaching
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science, grounded in the National Science Education Standards (National Research Council, 1996). In addition to the content focus, another aspect of ASIST differentiating it from most university-sponsored induction programs is that it was available to any first-year secondary science teacher in the region, not just teachers who had graduated from the universities’ teacher preparation programs.

Compared to the induction programs in place in many districts, ASIST could be classified as intensive, taking place over the course of a traditional 9-month school year (August-May) and allowing teachers to participate for up to 2 years. Monthly meetings pertaining to the teaching of science, monthly classroom visits to observe and provide feedback to the teacher or co-teach lessons, electronic communications, and travel to a state or national science conference comprised the program. Districts and grants provided stipends for teachers to participate in ASIST, as well as covering the cost of travel to conferences. During both years, program staff consisted of a university science educator, experienced science teachers from local districts, and graduate students who were former science teachers.

The effectiveness of current mentoring and induction programs is less clear. Ingersoll and Kralik (2004) recently reviewed over 150 empirical studies of induction and mentoring programs, finding only 10 that (a) evaluated the effects of induction in terms of well-defined, verifiable outcomes for the teachers who were mentored, and (b) compared the outcomes of mentored teachers to a control group of nonmented teachers. In general, the researchers found that these 10 studies provide empirical support for the claim that assistance for new teachers – mentoring programs, in particular – have a positive impact on teachers and their retention, although the degree to which these studies controlled for other factors that might have led to differences in outcomes between mentored and nonmentored teachers was limited.

In a concurrently released review of empirically guided induction literature, SRI International (2004) found that most studies attempting to link induction to teacher effectiveness tracked only one or two indicators of teacher quality (for example, teacher satisfaction, or more rarely, retention), typically employed weak measures (such as teacher self-reports), and had poor study designs.

In a recent study looking at the relationship between components of induction programs and outcomes, Smith and Ingersoll (2004) used a nationally representative sample of teachers to examine participation rates in various induction-related activities, as well as whether first-year teachers who participated in these activities – such as mentoring and collaborative activities with other teachers – were more or less likely to stay with their teaching jobs the following year.

The results indicated that beginning teachers who were provided with mentors from the same subject field and who participated in collective induction activities, such as planning and collaboration with other teachers, were less likely to move to other schools and less likely to leave the teaching profession after their first year of teaching. Further, this study suggested that the more components of induction experienced by a novice teacher, the lower the predicted probability of turnover while also noting that few teachers experience high intensity induction. This study suggested that “more induction” has a stronger impact on reducing the likelihood of teachers
leaving, but it does not address the quality of these induction components (time spent with mentors, whether or not the mentor observed and provided feedback on classroom lessons, whether or not the mentor received any training, etc.), factors that Kardos (2004) found associated with the job satisfaction of new teachers.

Although the work of Smith and Ingersoll (2004) supports the importance of having a mentor in the same field, they did not specifically look at the induction of science teachers. Recent research, however, by Luft, Roehrig, and Patterson (2003) has focused specifically on the early years transition of science teachers. These studies do not focus on the relationship between induction and retention specifically. They do, however, focus on induction components associated with broader teacher retention. For example, the researchers followed three groups (general, science-specific, and no induction program) of beginning secondary science teachers for one year and documented their beliefs and practices. At the end of the year, secondary science teachers in the science-focused support program implemented more student-centered inquiry lessons, held beliefs aligned with student-centered practices, and felt fewer constraints in their teaching than did the other two groups of teachers.

As this study highlighted the important role of continued content support in the experiences and practices of first-year secondary science teachers, these small-scale studies led to a larger National Science Foundation funded study (which is underway) following 120 teachers in four different induction programs over 3 years that will examine the impact of content-focused induction on retention.

Dunne and Newton (2003), in a review of the literature, claimed the following benefits of coaching and mentoring programs for science teachers: They enable teachers to (a) increase their knowledge, (b) improve their understanding of how to embed scientific inquiry into teaching, (c) increase their instructional competence, (d) share in the school’s norms of collegiality and experimentation, and (e) enhance their ability to deal more effectively with diverse individuals and different learning styles. Wojnowski, Bellamy, and Cooke (2003), in their comprehensive review of the literature on mentoring and induction and the retention of science teachers, identified another condition ameliorated by effective mentoring and induction: the negative effects of teacher isolation and the positive effects of opening classrooms and teaching to observation and scrutiny by supportive teachers.

WORKING CONDITIONS

As Johnson, Berg, and Donaldson (2005) pointed out in their comprehensive report, *Who Leaves Teaching and Why*, “The condition of work that matters most to them is their teaching assignment” (p. 55) This situation seems especially problematic for science (and mathematics) teachers at the secondary level, given the findings by Ingersoll (2002) that one fifth of science teachers and one third of mathematics teachers lacked a major or minor in their field. It should be noted that the problem is not with science teachers teaching out of their field, but that so many underprepared teachers are teaching science – and mathematics. However, it is just as true that “highly qualified teachers may become highly unqualified if they
are assigned to teach subjects for which they have little training or education” (Ingersoll, 2002, p. 5)

Partly as a response to concerns about teacher turnover rates, the North Carolina Professional Teaching Standards Commission developed a “working conditions survey” of public school teachers, counselors and administrators to determine perceptions of school environments, and piloted the survey in the winter of 2002. School professionals responded to questions about the following categories of the school environment: Time Management, Facilities and Resources, School Leadership, Personal Empowerment and Opportunities for Professional Development. A report of the survey issued to the North Carolina State Board of Education by the Education Commission of the States (Glennie, Coble, & Allen, 2004) showed very clearly that teachers’ self-reported working conditions were statistically less favorable in schools identified as hard-to-staff compared to schools in general. With the support of the Governor’s Office this survey has now become an essential resource in finding ways to improve the conditions of teaching in North Carolina.

The Center for Teaching Quality (CTQ) and its research examining working conditions in both North Carolina and South Carolina demonstrates “a clear but difficult lesson: if we want to improve the quality of our teachers and schools, we need to improve the quality of the teaching job” (Ingersoll, 2003b, as quoted in Hirsch, 2005a, p. 1). In 2004, the CTQ conducted a Web-based population survey of teachers in North Carolina and South Carolina. Empirical analyses revealed the huge impact of teachers’ working conditions on student achievement and teacher retention (Hirsch, 2005a,b).

In 2006, CTQ’s survey efforts expanded, conducting work in North Carolina, Nevada, Kansas, Ohio and Arizona. In North Carolina, 68% of the state’s teachers (n = 75,000) responded; response rates in the other states were over 50%. In 2007, 67% of Mississippi’s teachers responded to a statewide survey. Although the teacher responses cannot be disaggregated by subject area taught, the findings are compelling:

– In North Carolina, analyses of the 2004 survey revealed that both teacher empowerment and quality of professional development were statistically significant in explaining absolute retention.
– The CTQ report also showed that teachers’ responses are significant and powerful predictors of whether or not schools made Adequate Yearly Progress and performed well on the state’s school accountability model both in terms of growth and school designation (Hirsch, 2005a).

Analysis of working conditions survey responses conducted by the CTQ has revealed other results, most notably that teacher working conditions are important predictors of student achievement and that teacher working conditions make a difference in teacher retention. In the future these studies, which are now being conducted in a growing numbers of states, will examine how different subject area teachers, like those in science, view their working conditions – and how those working conditions affect student achievement and teacher retention.

In addition, researchers have documented and accomplished teachers have verified a number of key working conditions factors critical to both recruitment
and retention. For accomplished teachers to consider moving to or remaining at a high needs school, then the following factors need to be in place: (a) working for an effective principal who embraces teacher leadership, (b) working with a groups of like-minded and skilled colleagues, (c) being trusted to use their professional judgment, and (d) having access to needed curricular resources, class sizes, and student loads (Berry, 2007).

Clewell, Darke, Davis-Googe, Forcier, and Manes (2000) conducted a comprehensive review of state and district teacher recruitment programs. Although they documented a wide range of activities, they concluded that there was a lack of “evaluation data on the effectiveness of existing models of teacher recruitment in the research literature” (p. 76).

We know very little about science majors in higher education who might be interested in becoming secondary science teachers – and what barriers need to be overcome and what conditions need to be created to entice them to do so. Luft, Fletcher, and Fortney (2005) examined students who enrolled in the special university courses at the University of Texas-Austin designed to recruit secondary science, mathematics, and computer science teachers. The study showed that students with a high level of commitment tended to have prior experiences in education that were sustained over time. Indeed, one pool of potential science teachers are students majoring in science disciplines at the university. The UTeach program at the University of Texas-Austin provides, perhaps, the best example of what is possible.

One of the factors affecting teachers’ decisions to stay or leave a school – one that may differentially affect science teachers – is the quality of school facilities. In 1995, the General Accounting Office found, in a stratified random sample of 10,000 K-12 schools, that one third of schools with sufficient computers were not networked, and 40% of schools could not adequately meet the functional requirements for laboratory science.

Schneider (2003) found in a survey of teachers in Chicago and Washington, DC, that 60% of respondents said science labs were somewhat or very inadequate or nonexistent. Given the need for adequate laboratories, materials, and supplies necessary for teaching science, facilities matter to teachers and are a consideration in their decision to stay or leave a school – if not the profession. Indeed, a study by Buckley, Schneider and Shang (2004) found facility quality to be an important predictor of the decision of teachers to leave their current position – larger than their dissatisfaction with pay.

ACCOUNTABILITY AND TURNOVER

A state’s standards and accountability system can also influence teacher retention. Although few empirical studies have explored the relationship between standards-based reform and the commitment and retention of new teachers, some advocates of teacher autonomy have suggested that increases in standards, accountability, and testing are likely to decrease the commitment of teachers (Darling-Hammond, 1988; McNeil, 2000). Several recent studies, however, suggest that beginning teachers...
feel that they receive insufficient guidance about what to teach and how to teach it (Grossman & Thompson, 2004; Kauffman, 2004; Kauffman, Johnson, Kardos, Liu, & Peske, 2002), and that clear expectations aid new teachers in their transition to teaching. (Verdugo, Greenburg, Henderson, Uribe, & Schneider, 1997). Further, Smith (in press) showed that the strength of states’ standards, assessments, and accountability systems, as assessed by Education Week, was significantly associated with reduced turnover among beginning teachers.

MIDDLE GRADES: A SPECIAL CASE

Recruiting and retaining science teachers is a special problem in the middle grades – grades 6, 7, and 8. Fulp (2002) reported that approximately two thirds of middle school science teachers earned their undergraduate degrees in subject areas other than science or science education and that nearly half of all middle school science classes are taught by teachers who lack in-depth preparation in any science discipline. Making matters even worse, not even half of middle grades teachers report working with other teachers in their discipline to study or discuss science teaching on a regular basis. They are working in isolation from other teachers and without regular professional support of other teachers in their field.

Berns and Lawton (2004), researchers at the Center for Science Education at the Education Development Center, developed and piloted a mentor teacher program for middle grades science teachers in Massachusetts. They worked to create a learning environment characterized by trust and collegiality among the science teachers. In doing so they increased the middle grades teachers’ confidence in teaching inquiry science. They also learned how to inquire as colleagues into the issues associated with effective mentoring and being a mentee. The project is too new yet to determine an increase in retention of middle grades science teachers.

CONCLUSION AND CALL FOR MORE RESEARCH

Unfortunately, well-developed research on science teacher recruitment and retention, built on sound longitudinal databases, is thin. There is little reason to question that low teacher salaries contribute to the difficulties of retaining teachers, especially in science, but “one of the large unanswered questions…is how many prospective teachers never consider a career in education because of its low pay potential” (Johnson, Berg, & Donaldson, 2005, p. 55) The available evidence suggests that financial incentives, while necessary, are not sufficient for both attracting and retaining high quality teachers – including those in science.

In addition, although science teacher shortages continue to loom, all too little attention is being paid to what science teachers need for the 21st century. The discipline-specific courses offered by typical arts and sciences faculty in most universities may not be up to the task of preparing teachers to draw on interdisciplinary ideas and teaching strategies.

Also, the need to prepare elementary-level teachers to develop expertise in science will prompt new demand, requiring new incentives and resources yet to be
developed and documented. Even so, policymakers, researchers, and educators have not defined well what elementary school teachers need to know about science—and how many well-prepared science teachers of young children are needed. This information is much needed to confront the science teacher supply and demand issues facing American public education.

As more states draw on alternative routes into teaching to fill science vacancies, what kinds of teacher education do these teachers need? Alternative route candidates, despite their knowledge of subject matter and much-needed life experiences, also need significant training in what to teach and how students learn. The key will be to identify the critical elements—especially for 21st-century skills many are calling for American public school students to develop. In any case, much more needs to be known about what specific incentives are needed to recruit nontraditional candidates to science teaching. Working conditions are key to teacher recruitment and retention, but which ones are key for science teachers and how should they be operationalized?

With these issues in mind we call on additional research and action:

Research

Examine the specific conditions under which qualified and effective science teachers are attracted and retained in high need schools. The research needs to identify the barriers removed and the new conditions/incentives created (including provision of necessary materials, supplies, and laboratory facilities to support effective science teaching) to attract and retain science teachers. A template of common indicators and a set of questions on the background of new teacher recruits, program design elements, evidence of results, etc., should be developed and used for analysis.

1. Analyze the soon-to-be-released NCES 2003–2004 Schools and Staffing Survey (SASS) to examine trends on the background of recently hired science teachers and what they were doing prior to entering the classroom (for example, are they right out of college or did they come from a job in science?). These analyses could also update Smith and Ingersoll’s (2004) work on how induction/mentorship supports for new teachers influence retention in the context of mathematics and science teaching.

2. Analyze changes in state policies and reduction in science teacher shortages. The 1994–95, 1999–2000, and 2003–04 SASS databases could be used to analyze whether state policies targeted toward increasing the pool of qualified science teachers (such as expansion of alternative certification programs) are associated with reducing reported shortages of science teachers. This analysis could also examine whether increases in the strength of the accountability system and in teacher certification in different states during the 1990s affected shortages among science teachers in different states.

3. Conduct specific research on programs to attract current college students, as well as potential midcareer switchers to science teaching:
THE RECRUITMENT AND RETENTION OF SCIENCE TEACHERS

a. Develop and conduct a survey of university science students in their junior and senior years on the questions of barriers/conditions and their choice to become science teachers.

b. Develop and conduct a survey of potential mid-career switchers in order to better understand the questions of barriers/conditions and their choice to become science teachers.

c. Develop and conduct a study on the effectiveness of current recruitment programs like UTeach, identifying the barriers they have reduced and the conditions they have created as well as the success metrics of each.

4. Conduct a comprehensive survey or other research to identify the set of incentives and supports necessary to attract currently licensed and effective science teachers to high-need schools – and what might be best levers to entice those who have left teaching to return.

Action

1. Support the state and local database development so more fine-grained research and information gathering can be conducted and assembled.

2. Set up a network of science-focused teacher recruitment and retention program providers to share best practices.

3. Design a marketing campaign to assist policymakers in understanding the difficulties of recruiting, preparing, and retaining science teachers for the 21st century.

The last action step may be the most important. We have learned from our review that too many current efforts to solve the imbalance in science teacher supply and demand are built on conventional wisdom. New approaches engaging the science and mathematics faculty more directly, such as with UTeach (Coble, Walter, Anthes, Long, Erikson, & Somerville, 2006), and using designs developed by cutting-edge alternative providers, such as the Exploratorium, need to be considered and embraced. Conventional thinking and action will not begin to address the science teaching quality challenges America faces.

END NOTES

1 See author interview at http://yaleglobal.yale.edu/display.article?id=5581.

2 This finding has also been replicated using the nationally representative Schools and Staffing Survey, see Cohen-Vogel & Smith (2007).

3 For reviews of theory, policy, and research on teacher induction see, Feiman-Nemser (2003); Feiman-Nemser, Schwille, Carver, & Yusko (1999); Fideler & Haselkorn (1999); Gold (1999); Hegstad (1999).

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2. MODELS OF SECONDARY SCIENCE TEACHER PREPARATION

WHAT WE KNOW

Over the years, many have critiqued teacher education and made various proposals for the reform and improvement of teacher education. However, the research bases on which these proposals rest have often been underdeveloped, at best. In a current attempt to review research studies on teacher education, the American Education Research Association assembled a panel of leading teacher educators (Cochran-Smith & Zeichner, 2005). The resultant book, with 12 chapters and extensive bibliographies, used stringent criteria to identify high quality, trustworthy research studies. The writers looked at current work but also included relevant prior reviews and research. Even though the work did not focus on science teacher education, several chapters are relevant to this discussion. In a consideration of the politics and paradigms in teacher education, Zumwalt and Craig (2005) noted wide variation in the kinds of teacher education programs, as well as inconsistent program descriptions, making comparisons across programs difficult. In another chapter, Zumwalt and Craig (2005) noted that, to date, measures of teacher quality are crude, relying on indicators with limited precision and subject to influence by a number of factors other than the quality of the teaching. Also, solid research establishing links between the measures of teacher quality used and teachers’ performances in the classroom is lacking.

Floden and Meniketti (2005) reviewed research on the effects of coursework in the arts and sciences and in the foundations of education. They reported that the available research shows tentative and weak relations among the content courses taken by teachers, their subject matter knowledge, and students’ learning. The strongest links between subject matter knowledge and student learning have been found in mathematics, and even those are contingent on the level of mathematics being taught. Grossman (2005) identified several different pedagogical approaches advocated in teacher education, but found little research documenting the effectiveness of these approaches or how they worked.

WHAT WE HOPE FOR SCIENCE TEACHERS

Doing research on models of science teacher preparation requires a clarification of the aims and goals desired. What does the field expect new science teachers to know
and be able to do? Recent science teaching reforms for K-12 emphasize helping students develop deep conceptual understandings of content, conveying the nature of science, and engaging students in authentic scientific inquiry. Teachers must devise experiences that will help students construct understandings of natural phenomena. Science teachers must help all students to succeed; respecting and drawing productively on students’ diverse ideas, they must situate their students’ learning within the broader context of their school, neighborhood, town, city and the nation as a whole.

In order to prepare teachers to meet these expectations, there are over 1,000 secondary science teacher education programs in the country. Each program can be distinguished by its structure, admission requirements, curricular focus, and conceptual framework. According to Cochran-Smith and Zeichner (2005), these characteristics are pivotal to the discussion of teacher education programs because they influence the kinds of students who enroll, the experiences they have, and the kinds of continuing support available for them. Although some science teacher education programs are delivered by school districts or state departments of education, this chapter focuses on programs based in universities with substantial science and mathematics departments, because we aim to prepare secondary teachers with deep and current knowledge of their content areas.

Developers of science teacher education programs will have been guided, at least to some degree, by the national guidelines for science teacher preparation, as outlined in the National Science Teachers Association standards for the preparation of science teachers, the National Science Education Standards (National Research Council, 1996), and the Interstate New Teachers Assessment and Support Consortium (INTASC) standards for beginning teachers. Additional guidance is imposed by various accreditation bodies (e.g., the National Council for Accreditation of Teacher Education [NCATE] and the Teacher Education Accreditation Council [TEAC]) and state departments of education.

In this chapter a synopsis is provided of what is known about science teacher preparation based on published literature and our own research and professional experiences. The focus then shifts to the need for research on models for the preparation of secondary science teachers. The review volume edited by Cochran-Smith and Zeichner (2005) attempted to provide a productive direction for inquiries into the nature and impact of teacher education programs. Their extensive review covered the period 1986–2002 and provides the most comprehensive current review of teacher education programs. They concluded that much is still unknown about how teacher education programs affect the performances of their graduates and the pupils of these graduates. Their review noted the wide range of structures organizing teacher education programs at different institutions, a range that makes comparisons of programs difficult. Since research specific to science teacher preparation models is scarce, we extrapolate from the existing research on teacher education in order to address the preparation of teachers of science.
Teacher education programs are characterized in terms of their length (e.g., 1-, 2-, 4-, or 5-year program or 5th-year program), the level at which they are offered (undergraduate or graduate), and type of institution in which they are housed (i.e., community college, university, school district, or state or private agency). University-based programs vary widely; some take place in units that function primarily to prepare teachers, while others are situated in units focused on preparing scientists. Some programs are housed in universities with extensive graduate programs in a range of areas, some involve collaboration between community colleges and 4-year institutions, and some are in institutions with extensive teacher preparation efforts. The numbers of students enrolled in these programs vary greatly. In addition to a solely undergraduate teacher preparation program, five other types of teacher preparation programs have been identified by Arends, Winitzky, and Murray (1996):

- The extended and integrated 4-year program leading to a bachelor’s degree.
- The extended and integrated 5-year program leading to a bachelor’s degree and master’s degree.
- The 5th-year program leading to a master’s degree.
- The 6-year program leading to a master’s degree.
- Alternative certification post-baccalaureate programs.

In addition to these programs variations, a recent upsurge has occurred in university-based partnerships between science and teacher education faculty, as well as partnerships between universities and K-12 schools. The number and variety of alternative certification programs have also escalated (Feistritzer & Chester, 2003). Of course, as numerous reviews have noted, variability also exists not only across the institutions where teachers are prepared, but also within a given program. Variations can be based on location and the program’s attempt to meet the needs of the population being served. The program curriculum as envisioned and described by the teacher educator might not be reflected in the lived experiences of program participants. In order to obtain an accurate picture of the outcomes of a program, one needs to examine programs from the perspectives of teachers who experience them and of the classroom students taught by these teachers. Based, in part, on the political climate, reformers have argued for the elimination of teacher preparation programs, for the extension of the undergraduate degree in liberal arts followed by teacher preparation, and for the creation of alternative pathways into teaching.

As we examine the structure of programs, there are wide variations in the nature and quality of programs in different institutions based on the type of institution studied, the diverse goals and backgrounds of the faculty members who develop and implement the programs, and the state policy contexts guiding content and quality of programs. However, regardless of the programmatic variations, the following outcomes must be investigated in order to judge program quality:

- The development of teacher knowledge identified by Shulman (1986, 2004), including subject matter knowledge, pedagogical knowledge, and pedagogical content knowledge (see Abell, 2007).
- The ability of teachers to translate their knowledge into practice.
As science teacher education programs are designed, teacher educators are confronted with the fact that education in the U.S. is a state function; each state has its own ideas as to what should be taught to their children and how best to prepare its teachers. Education is a highly political venture, and all stakeholders have their own ideas as to what constitutes good and effective education. Changes in policies regulating teacher education are often made in response to societal needs, such as teacher shortages in certain areas. Research on teacher education often plays a much smaller role in design decisions. State mandates determine entry and exit requirements for most programs and the range of required course offerings and experiences. Some states (Texas, for example) have drastically limited the amount of education courses required as part of the teacher education curriculum. Some states use teacher candidates’ scores on mandated tests to make judgments about teacher education program quality. Some states develop their own tests, and others use widely available teacher tests. Some states require students to complete a major in the content area being taught, for example biology, while other states merely require a certain number of credit hours in that science. In all cases, teacher education programs must be responsive to state rules governing teacher certification.

Accrediting agencies also play a major role in the design of teacher education programs. For example, NCATE and TEAC, as part of their benchmarking processes, require teacher education programs to justify why a particular set of goals and program components have been selected by the science education community to frame the preparation of science teachers. The National Science Education Standards (NSES) provide a visionary framework for science teaching in precollege education, based upon the assumption that scientific literacy for citizenship should be a primary goal of science education. The NSES also indicate important aspects of teacher preparation programs.

Consistent with the vision of the NSES, the National Science Teachers Association (2003) developed Standards for Science Teacher Preparation. These standards require that science teachers should not only demonstrate that they have the necessary knowledge and planning skills to achieve the NSES goals, but also that they are successful in engaging their students in understanding the relationship of science and technology, nature of science, inquiry in science, and science-related societal issues. These NSTA standards are intended as the foundation for a performance assessment system through which teacher candidates must satisfactorily demonstrate their knowledge and abilities at several assessment points in the science teacher preparation program. The standards address the knowledge, skills, and dispositions deemed important by the NSTA for all science teachers. They are fully aligned with the NSES, consistent with the standards of the National Board for Professional
Teaching Standards (NBPTS) and INTASC and reflect the findings of the review by NCATE.

There seems to be some general agreement in the policy documents, in state guidelines, and in standards set by accrediting agencies and professional organizations about the expected components in a teacher education program. Although these components are enacted in different ways across programs, most science teacher education programs include requirements for

- Subject matter coursework, to provide deep understanding of science content and science processes.
- Educational foundations coursework, to broaden the appreciation of the factors and debates that shape education and schooling.
- General pedagogical coursework, to develop knowledge of general teaching strategies.
- Subject-specific pedagogical coursework to develop pedagogical content knowledge for science teaching.
- Early fieldwork prior to student teaching, to develop prospective teachers’ understanding of classrooms and students.
- Supervised student teaching experience, to provide a mentored apprenticeship.

Most programs also include some culminating project, such as a thesis, action research project, or portfolio that allows future teachers to synthesize and apply their knowledge. Programs for science teacher preparation are also guided by the conceptual framework of the faculty designers (Barnes, 1987; Russell & Martin, 2007; Tom, 1997; Zeichner, 1993).

A RESEARCH AGENDA FOR SCIENCE TEACHER PREPARATION PROGRAMS

Descriptive Studies of Science Teacher Preparation Programs

Research around teacher preparation programs has been problematic, given the wide variety in programs and the absence of program descriptions in most research (Zeichner & Conklin, 2005). Thus, a necessary first step in the research on science teacher preparation programs may be to create a taxonomy. A taxonomy of science teacher preparation programs would present the elements characterizing existing programs and generate a means to classify new programs. Developing a taxonomy would require researchers to pose questions to distinguish among program structures, such as the following:

- Where is the program housed? In a private organization or in an institution of higher education? In a college of education or a college of liberal arts? Where and how are decisions made about the program structure?
- At what point in their college careers do students begin the program? What degree(s) do they complete? How long are they in the program? What are the criteria for entrance into, continuation in, and completion of the program?
- What specific science coursework requirements exist for students in different certification areas? Are specific science courses required for future teachers?
Are these courses taught in a manner consistent with current reform efforts? Do all majors, not just those in education, take these courses?  
- What is the nature of the pedagogy courses taken by prospective teachers? Are these courses sequenced in any way? When do preservice teachers take these courses? Is there a cohort structure to these courses? Are there specialized methods courses for teaching science or general methods courses? Are there methods courses focused on the teaching of specific sciences?  
- How is early fieldwork (completed before student teaching) organized? Is it completed independently or as part of a course? In what settings does this work take place?  
- What educational foundations courses are required? How are these linked to other aspects of the program, such as early field experiences or pedagogy courses? When in their programs do preservice teachers complete these courses?  
- How is the supervised teaching experience organized? How long is it, who provides supervision, how are mentors selected, in what kinds of communities, schools, and classrooms does it take place?  
- Do preservice teachers complete a culminating project? What kind of projects are completed? What role does the project play in completion of the program?  

These questions could be answered through an analysis of published program requirements, with perhaps a few follow-up inquiries. These are programmatic aspects we would expect to be communicated to prospective students, since they are factors prospective students would use in making decisions about choosing a particular program. Answering these questions should provide at least a general taxonomy that would help to distinguish among programs by providing details about program structure that researchers often fail to communicate.

Other aspects of teacher education programs will be more difficult to determine. Some of them might be determined through a review of accreditation materials prepared by teacher preparation programs or interviews with key stakeholders. We recommend a case study approach, in the spirit of the Stake and Easley (1978) case studies of science classrooms, to develop case studies of science teacher preparation programs. Aspects research has indicated are important to high quality teacher education programs lead to a second set of questions to be addressed, including:

- What is the philosophical orientation that guided program development?  
- How are those philosophical tenets enacted in the program? How do course instructors, fieldwork and student teaching supervisors, and mentor teachers understand and enact the goals of the program and demonstrate its philosophical underpinnings.  
- How does the program ensure that fieldwork takes place in settings that model reform-minded teaching?  
- How does the program ensure that course and field work expose future teachers to the range of conditions in schools—helping them see the reality of schools, not just the optimal conditions?  
- How does course and field work provide opportunities to work effectively with diverse groups of students?
How do schools, science educators, and scientists collaborate in designing and enacting the program?

Answering these kinds of descriptive questions could be the initial stage in research on the quality of the programs studied. That research is the subject of the next section.

Program Quality Research

A major concern in teacher education is to determine which program models lead to better results in terms of teacher learning and, ultimately, the learning of their students. A taxonomy of science teacher preparation programs could make program structures explicit and frame studies of the quality of teacher education programs. The recent volume edited by Cochran-Smith and Zeichner (2005) contains several chapters delineating the kinds of studies needed to address questions of program quality. Generally, the authors call for studies that compare programs at different institutions in terms of outcomes for teachers and their students. How do prospective teachers progress through the teacher preparation programs? What kinds of science courses can help develop subject matter and pedagogical content knowledge? How well do the teachers who graduate from these programs implement practices effective in helping their students to learn? What are the facilitating and constraining factors in their implementation of reform-minded practice? How do all students in the classrooms of these teachers learn science?

The answers to these questions can come from a variety of research designs. For example, large scale projects can yield data about many programs and allow generalizations across programs. Naturalistic studies yield rich, in-depth data about fewer participants that are transferable to other contexts. Both types of studies will produce findings useful to the field. However, to be useful these studies need to be designed explicitly to elucidate program quality and be grounded in the taxonomy of program types. In terms of large-scale studies, we recommend within-state comparisons of different program structures across different institutions to compare outcomes on a number of dimensions. For example, examining teacher knowledge outcomes using common instruments across institutions identified by the taxonomy as having different structures, while controlling for the incoming characteristics of the future teachers, could inform the types of structures that help teachers learn. We also recommend studying programs that prior analyses indicate have features of best practice in teacher education (e.g., coherence, solid grounding in content-specific pedagogy, commitment to equity, use of reform-based teaching and materials) to examine the outcomes for teachers and their students.

Once we can characterize different programmatic structures, intensive case studies with a few programs having different structures and organizations would also be useful. Researchers would look at individuals entering these programs at different points in life (high school/college students; career changers; out-of-field teachers; individuals who temporarily try teaching as service learning or as a step in planning for other careers; or postbaccalaureates directly out of college) in order to learn about the various experiences of becoming a teacher. These in-depth studies...
could determine if key points in a program contribute to development as a teacher. Do particular biology courses, for example, consistently contribute to a new teacher’s understanding of the nature of the discipline? Are there key field experiences that contribute to a developing teacher’s abilities and motivation to work with a wide range of learners? How does student teaching in a setting with reform-based teachers contribute to a student teacher’s ability to implement reform-minded approaches? What kinds of support are necessary beyond the teacher preparation program? Clearly, some of these questions lead to longitudinal studies of teacher education students across programs and into the beginning years of teaching.

Science Teacher Preparation Policy Research

Too many writers treat teacher education as though it were a unitary and consistent enterprise, separate from the winds of politics. However, this view is far from reality. Not only do program structures differ greatly, political bodies regulating teacher education programs produce different program guidelines. Each state has its own policies and requirements for teacher preparation programs, influenced by federal mandates. We believe it is important to understand the policies that shape teacher education. For example, a decade ago states began witnessing a teacher shortage, especially in the areas of science. By 2003, most states had responded to the shortage by creating new guidelines for alternative pathways into teaching (Feistritzer & Chester, 2003). The research community needs to better understand how policy affects teacher education practice. We also need to better understand how research findings can influence policy. If we seek to change teacher education, it is important to understand the policy context in which education researchers work. We envision policy studies that would examine the following science teacher preparation questions:

– How is science teacher preparation regulated within and across different states?
– What is the relation between requirements for licensure programs and professional standards for new teachers? What are accreditation processes for licensure programs, and who implements them? What kinds of programs result from these regulations and processes? Are there states where policies and regulations are enacted strictly, and if so, does this allow for greater homogeneity in program structures and requirements?
– Within specific states, what is the transformation of intentions from policy makers to program designers to instructors? How do students interpret licensure requirements? How do mentor teachers interpret licensure requirements?
– How do accreditation agencies influence the views of program design help by policy makers, program designers, and program implementers? How do these agencies influence program quality?
– How are individual teacher education programs organized and governed? How do programmatic decisions get made? How are these decisions translated to those who are teaching and the enacted?
The field is ripe for descriptive, program quality, and policy research in the area of science teacher education. Current research and practice suffer from a lack of delineation of program structures. Funding agents should invest in the descriptive work of creating a taxonomy of science teacher preparation that can become the foundation of future research. Understanding how programs are structured, how policy influences practice, and the role of program structures in producing high quality teachers are critical issues for science teacher education researchers. A variety of well-designed research projects, including longitudinal studies of teacher learning, are needed.

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