EDUCATING TOMORROW'S SCIENCE TEACHERS

STEM ACT Conference Report: Research Section

A report on a working conference on
Alternative Certification for Science Teachers
held May 5-7, 2006 in Arlington, VA.

Authors

Allan Feldman	*University of Massachusetts Amherst*
Jodie Galosy	*Michigan State University*
Carole Mitchener	*University of Illinois Chicago*

Writing committee

Abdulkadir Demir	*University of Missouri, Columbia*
Allan Feldman	*University of Massachusetts Amherst*
Jodie Galosy	*Michigan State University*
Richard Iuli	*SUNY Empire State College*
Carole Mitchener	*University of Illinois Chicago*
Hsing Chi Wang	*University of Calgary*
Bruce Herbert	*Texas A&M University*

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Table of Contents

EXECUTIVE SUMMARY

The University of Massachusetts (UMass) STEM Education Institute and the UMass School of Education hosted a National Science Foundation funded conference entitled “Science, Technology, Engineering and Math—Alternative Certification for Teachers” (STEM ACT) in Arlington, Virginia on May 5-7, 2006. This white paper summarizes issues presented at the conference that are of importance for academic researchers of alternative certification (AC) for science teachers. It also outlines a research agenda for the initial preparation of science teachers, regardless of programs, which is intended to identify and examine how teacher learning occurs in their preparation, what is learned, and how teachers put that learning to use. Two similar papers have been prepared for program providers and policy makers.

Participants at the conference agreed that alternative certification is a wide-ranging term that fails to clearly delineate a unique set of programs. There are considerable variations in the design, structure and purpose of alternative certification programs, and it is of little value to compare and contrast traditional and alternative programs for the purpose of research on science teacher education. Using the geographical feature of the divide as a metaphor, the authors of this white paper describe the divides between science teacher education and generic teacher education, between pre-service and in-service teacher education, between licensure programs and educational programs. The authors then advocate the “reform vision” for science education and discuss the implications for teacher beliefs, knowledge and skills that support the reform vision.

The authors argue that science teachers need to learn and develop both explicit and tacit knowledge and skills particular to the teaching of science, and to a particular audience. They point out that the requirement of content knowledge specific preparation of science teachers is also due to the fact that science is not itself monolithic. The participants also suggest that what makes a difference to student learning with regard to science teacher education is not where teachers are in their professional careers, but rather teachers’ knowledge and skills; therefore, the divide between pre-service and in-service teacher education activities should be replaced by that between novices and experts. The authors compare programs with licensure of new teachers as the primary purpose with those centering upon education of new teachers, and recommend that programs should keep teacher learning at the center so as to maintain quality of teachers prepared while increasing productivity.

The “reform vision” of science classrooms and science teacher education that the authors describe unfolds the demands for science teacher beliefs, knowledge and skills. There is a growing consensus that science teachers need a depth and breadth of domain-specific content knowledge; they should understand science as a discipline, i.e., the nature of science (NOS), despite the fact that there is no single definition of NOS; and science teachers should develop pedagogical content knowledge (PCK), which still needs research that applies across contexts of teaching and learning and are context specific as well. Moreover, the authors incorporate studies on science teacher beliefs, scientific inquiry, students’ conceptual understanding, and formative assessment, to inform their investigation of early career science teacher development regarding their PCK.

In addition to a list of questions for future research, this paper recommends that, in order to know what and how science teachers need to learn to benefit their students in meaningful ways, and to materialize the “reform vision” of science education, rigorous research requires conceptual clarity, methodological support, and empirical warrants.

STEM ACT Conference Report

Research Section

Introduction

The major theme of the STEM ACT conference was to respond to the question, “What do we know and what more do we need to learn about how to incorporate the results of more than 30 years of research on science teaching and learning into alternative certification programs?” However, a review of studies that have compared alternative with traditional programs led us to the conclusion that given the wide variety in the structures of alternative and traditional programs, and the wide variety in the knowledge, skills, and dispositions that candidates bring to the programs, there is little that can be learned through research that attempts to compare alternative and traditional programs. Hence, in this white paper we argue that what is needed, instead, are studies that identify and examine how teacher learning occurs in those experiences; what is learned; and how teachers put that learning to use. In other words, this white paper’s primary purpose is to outline a research agenda for the initial preparation of science teachers, regardless of programs, which takes into account results of more than 30 years of research on science teaching and learning.

This white paper starts with issues related to defining alternative certification programs and research on such programs, which is followed by delineation of what we refer to as the “Reform Vision” of science teaching, and what and how science teachers would need to learn in order to construct reform vision classrooms. We conclude the paper with recommendations and questions for future research.

A list of all the papers presented in the research thread appears in the Appendix.

1. Defining Alternative Programs

One of the findings of the STEM ACT conference was that alternative certification is a wide-ranging term that fails to clearly delineate a unique set of programs. Many programs considered to be alternative programs are in fact housed in institutions of higher education and lead to both licensure and a degree. Others have chosen to call only undergraduate programs “traditional,” and to place all other teacher education programs in the category of alternative. In addition, there is at least as much variation within programs as there is between programs. For example, Marjorie Wechsler, in a paper delivered at the STEM ACT Conference, reported on a large scale study of alternative certification programs done with her colleagues at SRI International. They found large variations among alternative certification programs in the characteristics of participants (e.g., their education backgrounds), previous careers and classroom experience; and in the components of the alternative certification programs, including participant experiences with coursework, mentoring and supervision, and the context of their school placements (Humphrey, Wechsler, & Hough, 2006).

Similarly, in another conference presentation Sandra Abell and her colleagues (2006) reported that the literature indicates wide variation in the design and purpose of alternative certification programs (Darling-Hammond, 1992; Feistritzer, 1998). In particular they noted that

"Scribner, Bickford, and Heinen (2004) found differences in program goals, structure, support in teaching field placements, and mentoring available to interns among the various alternative certification programs within the state of Missouri (Abell et al., 2006, p. 3)." Abell at al. concluded from this that, "Because of this variation in program design, the research results are difficult to interpret and inadequate for informing the design and implementation of alternative certification programs (2006, p. 3)." Moreover, in a study of new science teachers in "Bayline" school district, Jodie Galosy noted that "even within this one district and alternative certification program, considerable variability existed across teachers, their school contexts, and their learning opportunities" (Galosy, 2006, p. 2). Michelle Lee also found wide variations among candidates in the alternative programs that she studied and that the candidates' perceptions of the program varied widely in terms of structure and cohesiveness (Lee, Olson & Scribner, 2006).

Thus, the large variations in program structure among those programs labeled as alternative, the differences in candidate backgrounds within and among programs, and the wide range in the school contexts in which candidates were placed, both within and among programs, led us to concur with the statement that "there is no agreement about the definition of alternative certification and there is some confusion as well about what constitutes traditional certification" (Zeichner & Conklin, 2005, p. 656). Given that the meaning of alternative (or traditional) certification "is obscure and its forms of implementation are many" (Fenstermacher, 1990, p. 155), research that contrasts alternative with traditional programs has limited ability to inform science teacher education. We argue that we need studies focusing instead on the educational experiences programs provide, what teachers learn from these opportunities, and the implications for their students. We expand on these points in the following section of the paper.

… much of the literature on alternative certification programs is in the policy domain, such as issues about who enters teaching through an alternative certification route, where they teach, and how long they stay. These studies pay little attention to teacher learning, the goal of teacher education programs

2. Research on Alternative Programs

Alternative teacher certification has become a proliferating phenomenon in the United States in the past two decades. Nonetheless, much of the literature on alternative certification programs is in the policy domain, such as issues about who enters teaching through an alternative certification route, where they teach, and how long they stay. These studies pay little attention to teacher *learning*, the goal of teacher education programs. Moreover, policy studies tend to look broadly at teachers and teacher education in general, often without a subject matter focus. That is, little or no attention is paid to whether the teachers will teach at the elementary, middle or high school level; or what subject area they will teach. This was confirmed by a thorough search of the literature in which we found few references to studies of alternative certification programs for science teachers. This is problematic because subject matter knowledge is considered an essential component to pedagogical and pedagogical content knowledge (Allen, 2003; Darling-Hammond & Youngs, 2002; EOTP, 2002; USDOE, 2002).

While science-specific studies of teacher learning are needed, equally valuable but less often discussed (or researched), is the importance of science teachers' knowledge of research findings on science teaching and learning, and how to use those findings in their classrooms. This includes studies of students' everyday and scientific understanding of science concepts (e.g., Clement, 1982; Driver, Guesne & Tiberghien, 1985), conceptual change (Posner, Strike, Hewson & Gertzog, 1982), and scientific discourse in classrooms (e.g., Clement, 1982; Crawford & Kelly, 1997; Driver, Asoko, Leach, Mortimer & Scott, 1994; Posner, Strike, Hewson & Gertzog, 1982; Rosebery, Warren & Conant, 1992[1]). There have also been large research programs on the teaching of science. These have primarily been in the areas of inquiry (Layman, 1996); the science, technology and society (STS) approach (Yager & Tamir, 1993); and the assessment of learning (Atkin & Coffey, 2003; Black, Harrison & Lee, 2004). Other research programs that have informed science teacher preparation include those on the nature of science (Lederman, 1992; Solomon, Duveen & Scot, 1992) and women and underrepresented groups in science (Brickhouse, Lowery & Schultz, 2000; Rodriguez, 1998). While there is more research needed in these and other areas of science education, the field would benefit from examining the impact these studies have on teacher education, teachers, and their students.

Accordingly, we recommend rephrasing the guiding question to "What do we know and what more do we need to learn about science teacher education that takes into account the results of more than 30 years of research on science teaching and learning?" That is, what and how do varied educational opportunities (for example, learning about research findings) contribute to the beliefs, knowledge, and skills that science teachers develop and to their students' learning? Such a shift moves away from the overemphasis on policy and licensure toward content-rich teacher learning across a teacher development continuum.

3. The Terrain of Science Teacher Education

In the preceding section we argued that it is of little value to compare and contrast traditional and alternative programs for the purpose of research on science teacher education. However, in order to put boundaries on the scope of this white paper there is a need to locate it as best we can among the various contexts in which science teacher learning occurs. In doing so we begin by thinking about the field of science teacher education in terms of terrain, and then by focusing on one type of geographical feature – the divide. In research on science teacher education the divides that we are concerned with are those that separate science teacher education from the education of other teachers, those that separate preservice and inservice teacher education; and those that separate programs that have as their primary purpose teacher licensure from those that have as their primary purpose the education of teachers. We particularly like the metaphor of the geophysical divide because rather than a clear line, the divide is often a long ridge that separates watersheds. For example, when rain falls near the continental divide that separates the Colorado and Mississippi watersheds, it will either eventually flow into the Sea of Cortez or the Gulf of Mexico, depending on which side of the divide it falls on. However, because so little rain actually falls exactly on the "dividing line" its precise location is not important except to a small number of hydrologists. Instead what is important is whether the rain drops head toward the tributaries of the Colorado or to those of the Mississippi. In the same way we are not too concerned with surveying exactly the divide between our categories, but rather which side of the divide we examine.

[1] C.f., National Research Council (2005) for a summary of studies on student learning.

3.1 Divide between science teacher education and generic teacher education

The first divide that we examine is between programs that focus on the preparation of science teachers and those that are more generic. A major part of our argument in this white paper is that science teachers need to have knowledge and skills particular to the teaching of science and that these knowledge and skills go beyond those that can be learned and developed without paying attention to what it means to teach and learn science. In addition, there is the difference between the content knowledge of school science and that of the academic disciplines, between what is practiced by scientists and what is presented to college students (Hill & Ball, 2004; Stengel, 1997). This is further compounded by the fact that science is not itself monolithic. Each of the sciences has its own substantive and syntactic structures (Schwab, 1978) that determine what is known and the warrants for knowledge.

3.2 Divide between preservice and inservice teacher education

A second divide is between teacher education activities that occur before candidates are hired as teachers of record and those that occur after they enter the teacher workforce. The divide between preservice and inservice teacher education, especially in the early years of practice, has become more of a wide plateau than a mountain ridge as the models for initial science teacher education proliferate. Just as we found that it is not useful to distinguish between traditional and alternative teacher education programs for the purpose of research on science teacher learning, we believe that it is not fruitful to continue to try to maintain the distinction between preservice and inservice teacher education. Rather, it may be better to distinguish between novices and experts in studies, because the distinction has more to do with the level of knowledge and skills that they have, rather than where they are in their professional careers.

3.3 Divide between licensure programs/educational programs

The third divide that we examine is between programs that have as their primary purpose the *licensure* or *credentialing* of new teachers and those that have as their primary purpose the *education* of new teachers. In their extreme forms, the former exist solely to help candidates meet the minimum requirements of state licensing agencies, while the latter help teacher candidates to develop the knowledge, skills, judgment and wisdom for teaching. The advantages of the former are that they require minimal resources to run the programs, and keep the cost to the candidates low, especially in terms of income lost while otherwise enrolled in the program. They also quickly produce the teachers that are needed in high demand regions. What we are calling teacher education programs, on the other hand, require many more resources, because they recognize that time and effort are required to produce knowledgeable, skilled, and wise practitioners. A challenge in science teacher education is how to design programs that have the benefits associated with credentialing programs yet prepare teachers to be effective science educators. Much research on science teacher learning must be done to make sure that as programs are trimmed to increase productivity, they maintain the quality that keeps teacher learning at the center.

We now look more closely at science teacher education by delineating the “reform vision” for science education that guides most of the research in science teacher education. We then turn to the teacher beliefs, knowledge and skills that support the reform vision, and then to ways that teacher education can be embedded in practice.

4. Visionary Strides: What And How Science Teachers Need to Learn

What science teachers need to learn is inextricably linked with our vision of science education. In the following section, we consider contemporary visions for science education and their implications for teacher learning. We describe what educational reformers imagine, the implications for what science teachers — particularly those new to the profession — must learn, and the research progress, to date.

4.1 A reform vision of good science teaching

Over the past decade, the science education community has developed a vision for science classrooms where all children have opportunities to develop deep understanding of science and its practices. This vision imagines science classrooms as active and exciting places; where science is relevant and interesting to students' lives, awakens their curiosity about the world within and beyond their own experience, engages them in scientific inquiry, and deepens their commitments to responsible citizenship.

These hopes for what science education could be stand in sharp contrast to descriptions of science classrooms students typically encounter — often depicted as dull, boring places dominated by lecture, incomprehensible textbooks and worksheets, and punctuated with occasional laboratory procedures which — when followed precisely — yield pre-determined results. Moreover, all learners do not have equal opportunities to participate in and/or experience success in science, as evidenced by achievement gaps between some racial, ethnic, and economic groups (Lynch, 2000).

4.2 What do science teachers need to learn to construct Reform Vision classrooms?

Visions are ideological; school classrooms are not. Studies point out the strenuous demands that instructional reforms, like those proposed for science, exact on experienced teachers, let

alone novices (Gamoran, Anderson, Quiroz, Secada, Williams & Ashmann, 2003; Kennedy, 1998; National Research Council, 2000). Ambitious visions for classroom science teaching and learning have profound implications for teacher learning — expectations for what teachers know and are able to do expand accordingly (c.f. NSTA, NSES, NBTS, INTASC). Science teaching becomes more complex and demands much from teachers, especially those at the beginning of their careers. The lists of beliefs, knowledge, and skills considered necessary are lengthy: deep understanding of science and scientific practices, pedagogical and pedagogical content expertise, knowledge of learners, and capacities for context-specific judgment and reasoning, to name a few. Consider, for instance, the range of beliefs, knowledge, and skills included within the research papers for this conference (see Table 1).

Science education research continues to pursue meaningful lines of discipline-specific inquiry — like those represented at the STEM ACT conference — with implications for science teacher preparation. For instance, we now have a much better grasp of how students develop conceptual understandings of a wide variety of science concepts (c.f., research studies on conceptual change). Other promising lines of work include, but are not limited to, teacher content knowledge, learners' views of science, and student assessment. However, we know little about the impact of incorporating this scholarship into early career science teacher education. That is, what are the implications for teachers and their students?

Consequently, empirical warrants for what good science teachers must know are emergent, at best. Progress requires long-term, coordinated commitments from the science education research community to investigate relationships between science teachers' professional development, their beliefs/knowledge/practices and what their students know and are able to do. This is the agenda for research on *any* program invested in science teacher *education*, regardless of designation (e.g., alternative, undergraduate, graduate, etc.). We now consider research progress on *what* science teachers need to learn.

Table 1. Teacher learning outcomes referenced in STEM ACT research papers

Paper/Poster lead authors	Beliefs/knowledge/skills/practices
Abell	Content knowledge for teaching (CKT) and Pedagogical content knowledge for teaching (PCK)
Demir	Inquiry-based teaching practices
Dern	Teacher beliefs about student-centered teaching practices
Galosy	Teachers' expectations for their students' science learning
Greenwood	Teacher efficacy — belief that they can have positive impacts on student learning
Lee	A range of science teaching practices (active learning, collaborative learning, connecting science with students' experience, addressing students' misconceptions and learning difficulties, assessment)
Mitchener	Inquiry-based teaching beliefs and practices
Sterling	Classroom management, planning, and instructional capacities

4.3 Teacher beliefs, knowledge, and skills that support the Reform Vision

In their review of research on professional development, Wilson and Berne (1999) suggest that getting at the "what" of good teaching entails both conceptual and empirical work. We see the vision for science teaching already discussed as the kind of conceptual work necessary. The thirty-year history of science education research provides some empirical footing. However, studies that examine the results of teacher education and especially research that links teacher and student learning are needed. Moreover, if we are to characterize and test models of teacher and student learning we need more robust conceptual and methodological tools for our work. We draw on the STEM ACT research presentations to offer some examples of the kind of research and tools we mean; discussing, in turn, teachers' content and pedagogical content knowledge, inquiry-based teaching, students' conceptual development, and the nature of science.

4.3.1 Science teacher content knowledge

The candidate's science background is the most shared focus across research papers presented at the STEM ACT conference. Galosy (2006) highlighted the critical importance of this knowledge as one of the personal resources that three STEM-degreed teacher candidates relied on to access and effectively use a variety of other available resources. Similarly, Mitchener (2006) argued that this STEM background played a significant role in beginning teachers successfully conducting action research projects during their second years to improve their teaching. Abell et al. (2006), Herbert (2006), and Wang (2006) all focused more specifically on the teacher candidate's content knowledge, and what and how the formal and informal aspects of this knowing becomes accessible to students.

The work of Britton and colleagues (2006) support a growing consensus that science teachers need a depth and breadth of content knowledge that college science courses alone are unlikely to provide.

The work of Britton and colleagues (2006) support a growing consensus that science teachers need a depth and breadth of content knowledge that college science courses alone are unlikely to provide. Their studies suggest content for science teaching is domain-specific in at least two ways – 1) to the particular science discipline and 2) to the work of teaching itself. It is clear that teachers need to know the science that they will teach – a major in biology will not provide the content knowledge needed to teach earth science. Moreover, drawing on the work of Ball and colleagues in mathematics (Hill & Ball, 2004), Abell et al. (2006) note that the content knowledge for teaching may be qualitatively different from that required for a career as a research scientist or engineer. Contrary to typical assumptions, then, teacher candidates with science majors or previous career experience in science-related fields may not necessarily have the right content knowledge for science teaching. In fact, Wang (2006) — citing Lederman and Gess-Newsome's work (1999)— implicates college-level science courses as major contributors to the fragmented and shallow "knowledge structures" evidenced by many secondary science teachers (pp. 13-14).

Yet, as Wang (2006) points out, studies investigating secondary science teacher content knowledge reveal little about what constitutes "good training in science" (p. 11) for science teaching. Previous studies of teacher content knowledge often are not domain-specific; using proxies, like number of science courses, for teacher content knowledge. Further, other commonly-used measures, like teacher or mentor reports of content confidence/competence have suspect validity. More robust measures for assessing domain-specific teacher content knowledge are needed; there are several NSF-funded works in progress to develop such measures (e.g., Abell et al., 2006; Kern, Roehrig & Luft, 2006).

More importantly, the idea that content knowledge for teaching is significantly different from the academic knowledge of the university (Hill & Ball, 2004; Stengel, 1997) suggests that teachers must continue to learn their subject within the context of their practice if they are to become experts. We believe that studying how teachers develop this expertise is a potentially fruitful and important area for research on science teacher learning.

4.3.2 Nature of science

Science education reform documents, such as the AAAS Benchmarks (AAAS, 1993) and the National Science Education Standards (National Research Council, 1996), frame science as both a body of knowledge and a process for developing that knowledge (often referred to as the "Nature of Science' or NOS). NOS experts contend science textbooks' treatment of "the scientific method" mislead teachers and students about scientific disciplinary practices. Consequently, if science teachers are to help students develop more realistic views about science, the teachers, themselves, will need to understand science as a discipline.

Attempts to measure NOS have a long and contested history (Lederman, Schwartz, Abd-El-Khalick & Bell, 2001; Munby, 1983). However, efforts to develop national science standards have contributed to a growing consensus about practices that characterize scientific work; and practices students (and their teachers) should have opportunities to understand and experience. In turn, these scientific practices form the basis for instruments intended to measure NOS. Research into NOS development in science teacher education has been facilitated by recent validation studies of NOS instruments (Lederman, et al., 2001).

While there is no single definition of NOS, reform documents emphasize some common characteristics of scientific work: "Scientific knowledge is: tentative (subject to change), empirical, theory-laden, partly the product of human inference, imagination, and creativity…and socially and culturally embedded" (Abd-El-Khalick, 2005, pp.16-17). Studies of pre-service teachers, to date, show most teacher candidates have limited understanding of NOS. Moreover, even when their views more closely represent those described above, the "translation of these views into instructional practices was, at best, limited and mediated by several factors" (Abd-El-Khalick, 2005, p.16). However, we know little about the impact that teachers' knowledge and beliefs have on their NOS understanding and classroom practice. STEM ACT Conference participants did not address NOS explicitly in their work. However, Greenwood and colleagues (2006) do note that given present efforts to attract STEM graduates to teaching, STEM training, work history, and especially experiences doing scientific research bears further study. In addition to the implications these prior experiences have for teacher preparation and support (as Greenwood et al., 2006, suggest), another interesting line of inquiry is how these prior experiences influence teacher learning about NOS and classroom instruction.

4.3.3 Science teacher pedagogical content knowledge

Research on science teacher pedagogical content knowledge (PCK) parallels content knowledge — we have fledgling understandings of what “it” is and thus, few valid measures of “its” assessment. In their literature review on the construct, Kern, Roehrig and Luft (2006) draw on Shulman’s (1987) work and describe pedagogical content knowledge as “the capacity of a teacher to transform the content knowledge he/she possesses into forms that are pedagogically powerful and yet adaptive to the variations in ability and background represented by the students” (p. 7). Again, as with content knowledge, the challenge is translating this general description in context-specific terms. For instance, what does pedagogical content knowledge of a novice science teacher “look like” when teaching force and motion to a diverse group of seventh grade students? We suggest, then, that the field not only needs research that applies across contexts but also context-specific studies.

Not surprisingly, given what we yet have to learn about content knowledge for science teaching, researchers are grappling with how to examine PCK. Several STEM ACT research groups — led by Greenwood, Britton, Kern, and Abell — included PCK measurement in their work. We briefly describe each of their approaches to data collection and analyses.

Greenwood and colleagues (2006) evaluated the PCK of new science teachers with a survey questionnaire that they administered to the novice’s mentors. There are twenty-seven items in the questionnaire’s PCK scale that includes a range of criteria from laboratory safety to lesson planning to teacher enthusiasm. Although the PCK scale has high internal consistency (Cronbach’s alpha = 0.952), the questionnaire has only been used, to date, to collect mentor teachers’ perceptions of their mentees.

As part of their national study of induction programs, Britton’s (2006) research team used a combination of several classroom observations and interviews to assess PCK development in the following areas:

- multiple ways of representing content
- constructing content- and student- appropriate tasks
- understanding specific content within the disciplinary and curricular contexts
- identifying students’ prior knowledge
- understanding student errors and addressing student misconceptions
- assessing student understanding.

Kern and colleagues (2006) used some of the categories Britton’s group identified in their investigation of beginning secondary science teachers’ PCK. Kern conducted beginning and end-of-year semi-structured interviews and coded them with rubrics that were developed by Luft and colleagues (Lee, Puthoff, Luft & Roehrig, 2005). These measures delineate “three levels of proficiency within two broad categories of knowledge: student learning in science (use of students' prior knowledge, variations in students' approaches to learning and students' difficulties with specific science concepts) and knowledge of instructional strategies (level of inquiry and different representations of content)" (p. 13).

Abell's (2006) group also used Luft and colleagues' rubrics (cited above) to analyze PCK development in their study of early career secondary science teachers. In addition to interviews, Abell's data collection involved a series of lesson planning tasks — both hypothetical and within the teachers' classrooms — over time. In addition to knowledge of student learning and instructional strategies, Abell's group is developing PCK rubrics for other areas of interest, including assessment of student understanding.

Looking across this work on PCK, we see a consensus about what kinds of knowledge fall within the domain of PCK and the beginnings of some shared measures for guiding research. Both are important for a successful research agenda on early career science teachers and PCK. At the same time, STEM ACT participants also noted that most of this work relied on intensive data collection over time and development of case studies. Understandably, investigating PCK — content- and context-specific as it is — may well require case study designs. It also seems likely that investigating PCK development as a continuum necessitates longitudinal studies. We take up the implications of these research designs in our recommendations. We now consider several other lines of work that also inform research into early career science teacher development regarding their PCK, including teacher beliefs, scientific inquiry, students' conceptual understanding, and formative assessment

4.3.3.1 Teacher beliefs

Growth in science knowledge and science knowledge for teaching is not the only one way to think about growth in expertise (Feldman, 2002). There is also the sense of becoming and the changes in self-identity that occur in the transition from novice to expert that leads to the ability to say with confidence, "I am a science teacher." For instance, Greenwood and colleagues (2006) investigated the influence that various types of feedback from a college supervisor had on three early-career science teachers' self-efficacy and noted that more research in this area was needed. They found Bandura's (2001) self-efficacy scale a useful instrument and recommended further work into the relationship between specific mentoring and supervisory practices and teachers' sense of self-efficacy. While Greenwood et al's rationale for studying self-efficacy is its relationship to teacher retention (citing Glickman and Tamashiro's 1982 study), investigating the influence of teacher self-efficacy on teaching practices and student learning would be equally valuable.

However, although inquiry stands as a marker of reform pedagogy, it is a complex notion, neither uniformly understood nor easily translated into classroom practices.

Kern et al. (2006), Galosy (2006), and Mitchener (2006) also considered the role teachers' beliefs play in their expectations for students and teaching practices. As a whole, these studies and others reviewed by Clift and Brady (2005) concluded that prospective teachers entered teacher preparation with their own firmly held beliefs and values about science, teaching, and learning, much of which related to their own schooling. Like their future students, what they learned, in this case through teacher education, was mediated by these prior beliefs and values derived from prior life and education experiences. Given the important role that efficacy, identity, and teachers' beliefs about science, teaching and learning play in teacher education, attention to this area, especially with regard to professional development, classroom practices and student learning is needed. Such studies would strengthen our understanding of what kinds of educational opportunities help teachers develop beliefs consistent with effective science teaching.

4.3.3.2 Scientific inquiry

Scientific inquiry figures prominently in reform documents, such as the *National Science Education Standards* (National Research Council, 1996), and its follow-up, *Inquiry and the National Science Education Standards* (National Research Council, 2000). However, although inquiry stands as a marker of reform pedagogy, it is a complex notion, neither uniformly understood nor easily translated into classroom practices (National Research Council, 2000). Confusion about inquiry is exacerbated by its double meaning in the NSES — as a learning goal for students and as a teaching strategy or method. The 2000 document reminds us that "inquiry" is not just about teaching but also refers to understanding how the scientific community builds knowledge:

> When educators see or hear the word "inquiry," many think of a particular way of teaching and learning science. Although this is one important application for the word, inquiry in the Standards is far more fundamental. It encompasses not only an ability to engage in inquiry but an understanding of inquiry and of how inquiry results in scientific knowledge. (National Research Council, 2000, p. 13)

Clearly, if students are to learn what inquiry means, learn how to engage in inquiry, and learn through inquiry-based teaching methods, then teachers will need the knowledge and skills to make that happen.

Research reports at the STEM ACT conference noted the connection between teachers' understanding of inquiry and the opportunities they made available for their students. Teachers tended to have partial and fragmented views of inquiry; associating inquiry, for instance, with "hands-on" activities (Demir, 2006) or using inquiry and activity interchangeably in instructional goals and practice (Galosy, 2006). Teachers with limited understanding of inquiry tended not to espouse inquiry-related student learning goals (Demir & Abell, 2006; Galosy, 2006; Lee et al., 2006). However, more sophisticated knowledge of inquiry did not necessarily translate into classroom instruction. Even when teachers did appear to have more complete understandings of inquiry, their classroom practices did not necessarily reflect their knowledge — they were hesitant to incorporate inquiry-based teaching due to management concerns, perceived school priorities, and/or time for planning (Demir & Abel, 2006; Galosy, 2006; Lee et al., 2006).

What new teachers know about inquiry, then, appears to be an important factor in the opportunities students have to learn about, and from, inquiry. However, there are a number of other variables that may be equally influential in making inquiry-based experiences more prevalent in science classrooms. For instance, how might a decreased course load influence novice science teachers' willingness to pursue inquiry-based instructional methods and what are the implications for their students? Classroom research can provide the evidence necessary to ensure policies and programs that not only support early-career science teachers' knowledge of inquiry but pay equal attention to factors that impact the extent to which investment in teacher learning improves student learning.

4.3.3.3 Students' conceptual understanding

Knowledge of the conceptions that students bring to the science classroom – including what have been called "misconceptions" – is often included as an aspect of PCK (see the earlier discussion on PCK). Research into student conceptions in physical, earth, and biological systems has been quite extensive over the years.[2] Yet we know little about the effect that incorporating findings from this research into teacher preparation programs can have on teachers' instructional practices or student learning. In one study from the conference, Lee et al. (2006) found that first year teachers who were simultaneously taking teacher education courses were somewhat more likely to address students' conceptions in their lesson planning if their coursework also did so. However, the factors that influenced how new teachers made use of this line of research, and the learning opportunities they created for their students as a result, require further examination.

4.3.3.4 Formative assessment

One area in which teacher education has paid particular attention to student conceptions research is formative assessment. This line of work includes studies on teaching that begin with an assessment of student's prior knowledge, and proceed with the design and modification of one's teaching in light of that prior knowledge. It also includes studies that focus on the preparation of teachers to investigate students' ideas about key concepts within science, and to be able to discern alternative conceptions that students hold from their informal experiences with science. In addition, future teachers are taught to engage in ongoing assessments of student learning to diagnose what conceptions of science their students hold, and how their teaching changes those pre-existing and developing conceptions. Although past efforts have focused on the use of instruments such as concept maps and webs or the use of clinical interviews (Mintes, Wandersee & Novak, 2000), more recent studies are examining the use of formative assessment by teachers to inform their practice (Atkin & Coffey, 2003; Black, Harrison & Lee, 2004; Feldman & Capobianco, 2003).

In summary, given the demands of science education reform, the list of what teacher education must prepare science teachers to know and be able to do is extensive. While this is not surprising—after all, science teaching is complex and multi-faceted—it does present difficulties for setting a coherent, yet comprehensive, research agenda on the content science teacher education ought to include. While we have pointed to several key areas discussed during the STEM ACT conference, there are other essential issues we have missed or touched on lightly; most notably, supporting diverse learners' science understanding and engagement. All of these lines of inquiry into science teachers, beliefs, knowledge, skills, and practices seem equally important for understanding science teacher preparation. The task then does not seem to be about setting priorities that choose one aspect of teacher learning over another. Rather, the challenge is to ensure that the evidence we are accumulating demonstrates if, and how, these areas influence teacher and student learning. We look more closely at what such work requires in our

[2] For example, see the bibliography assembled by Reinders Duit (http://www.ipn.uni-kiel.de/aktuell/stcse/stcse.html) that contains over 7700 entries.

recommendations. First, however, we turn from the content of science teacher education to review what conference participants presented and discussed about its' pedagogies—*how* science teachers learn.

5. Science Teacher Education Embedded in Practice

The second divide that we highlighted was between preservice and inservice teacher education. We suggested that this distinction be set aside and instead that researchers examine the ways that teacher expertise grows in all settings. Given that the STEM ACT Conference focused on teacher education programs, it is not surprising that most of the research reported on practice-based teacher education, particularly induction programs and mentoring in the first few years of teaching (see Table 2).

As early as 1975, Lortie concluded that school socialization overpowers what is learned in university preparation. Almost twenty-five years later, Kennedy (1999) characterized teacher education as still struggling with what she called, "a problem of enactment": the continued difficulty of beginning teachers putting into practice what they learned in their pre-service education. Yet several factors appear to be making inroads in understanding the nature of this problem and working to counteract it. A structural change most commonly referenced in this regard is "induction and mentoring"—a colloquial phrase within the profession that highlights the importance of the first three years of teaching. Induction, along with its assumed complement, mentoring, has grown over the last thirty years to become commonplace, and often state legislated, in many public schools (American Federation of Teachers, 2001). Generally, induction and mentoring policies call for school-based support that may be delivered individually or in groups to beginning teachers to assist with their classroom teaching and socialization to school practices and policies. A school or local university, often in combination with schools, districts or other education agencies may administer an induction program. Therefore, mentors can be district/school professionals, university personnel, or both.

Table 2. Teacher education experiences referenced in STEM ACT research papers

Lead author	Pedagogy/pedagogical tools
Abell	Guided and independent internship models
Britton	Science-specific mentoring and field experiences
Demir	Inquiry-based experiences
Galosy	Mentoring, coaching, workshops, literacy strategies
Greenwood	Mentoring, field supervision
Mitchener	Action research
Sterling	Coursework, classroom coaching
Wang	Coursework, field experiences, inquiry-based instruction

Clift and Brody (2005) concluded that, in general, partnerships between universities and schools on professional development decreased the potential discrepancy between what beginning teachers learned during their formal education and got enacted through their practice in these beginning years. These types of partnerships and the nature of mentoring during this induction period was a major theme across many research papers presented at the STEM ACT conference. Given that some teacher preparation programs do not have formal student teaching experiences (e.g., teacher candidates hold full-time teaching positions while also attending teacher education programs), induction and mentoring practices often replace traditional notions of student teaching. Consequently, induction/mentoring support takes on heightened priority for these early-career science teachers.

However, similar to observations of alternative certification programs, induction and mentoring practices widely vary, both between and within programs. The beginning science teachers Galosy (2006) observed, for instance, had very different kinds of support available to them. For example, some had science-specific mentoring, coaching, and workshops; others had limited access to science-specific support. Further, Galosy found teachers who had context-specific assistance (e.g., matched to subject, grade-level, setting) tended to develop more ambitious goals for their students.

Britton's (2006) review of induction support emphasized science-specific content and pedagogical content knowledge. Britton's conference presentation highlighted the tendencies to oversimplify what such a mentoring approach entails and the complexities of putting it into practice. In general, he called attention to the need to balance general mentoring needs with subject-specific ones and attempted to demystify three common *oversimplifications* in studies of science-specific induction. These oversimplifications include:

1. Induction programs must only address general needs of first year teachers, or else they will not survive.
2. Credentialed science teachers and career-switchers from industry do not have any content needs.
3. First year teachers cannot cope with an induction program focused primarily on content.

Within this same vein, Galosy (2006) warns that while teacher educators often fear putting beginning teachers in a "sink or swim" situation, this fate can also occur when overwhelmed by too many competing support resources, as much as from a lack. Balancing support, then, also requires coordination between individuals and programs offering assistance; something Galosy found often did not happen in the district she studied.

Additional conference research papers also addressed mentoring practices. Greenwood et al. (2006) examined the types of interactions college supervisors had with new science teachers and noted the importance of matching interactions to individual teacher characteristics and needs. Koballa, Bradbury, Deaton & Glynn (2006) also considered teachers' needs by studying the kinds of mentoring beginning teachers prefer. Specifically, they explored whether the previous experiences of these teacher candidates and the immersion aspect of their teacher preparation would impact the type of mentoring beginning teachers preferred and needed. They found that there is no one accepted view of mentoring, and that new teachers and their mentors had at least three different conceptions of the mentoring relationship: mentoring as apprenticeship; mentoring as personal support; and mentoring as co-learning. They also found that prior life and professional experiences play an important role in the formation of conceptions of mentoring, and, therefore, also in the formation of the relationship that develops between mentor and mentee.

Looking more broadly at mentoring practices, Humphrey, Wechsler and Hough (2006) found effective programs "provide trained mentors who have the time and resources to plan lessons with candidates, share curricula, demonstrate lessons, and provide feedback after frequent classroom observations". Recommended structures that facilitate mentoring include partner pairings (Wang, 2006) and co-teaching (Tobin, 2006). Given the scarcity of inquiry-based pedagogy in most schools, continued research on methods like these where new teachers and mentors work out teaching practices together in the classroom, would benefit teacher education. Clearly, there is much to learn about how teacher expertise grows for both partners in the mentoring relationship, especially in terms of subject-specific knowledge and skills that are required for reform vision science teaching.

There are other contexts in which teacher learning occurs. The most common form is the inservice course or workshop, which for most part, have been shown to have little effect on teachers' practice (Bransford, Brown & Cocking, 1999). However, large-scale studies of science teacher professional development indicate that sustained, ongoing experiences (e.g., lesson study addressed below) hold more promise. Science teachers also have had the opportunity to participate in ongoing scientific research projects through programs such as the NSF's Research Experiences for Teachers. While there have been several studies done on science teachers' research experiences (Brown, Bolton, Chadwell & Melear, 2002; Feldman, Rogan-Klyve & Divoll, 2007; Westerlund, Schwartz, Lederman & Koke, 2001), there is still much to be learned about how and what teachers learn as a result of these experiences.

Finally, we turn to what may best be thought of as inquiry learning experiences for teachers such as lesson study and action research. While there has been some exploration of lesson study as a form of teacher education for math teachers (Curcio, 2002; Fernandez, 2002), there has been little research on its use by secondary science teachers. Researchers have attended more closely to science teachers' conducting action research. At the STEM ACT conference, Mitchener (2006) shared that after a first year of overwhelming challenges, second-year teachers introduced to action research were able to take advantage of this pedagogical tool in crafting a practice anchored in learning-based principles. Other research on action research by science teachers includes studies by Capobianco (2006), Feldman (1994, 1995, 1996), Feldman & Minstrell (2000), and Van Zee (1998). Roth (2007) reviews studies of action research in the most recent *Handbook of Research on Science Education* (Abell & Lederman, 2007). Additional inquiry into lesson study and action research with beginning science teachers that focused on teacher and student learning would enhance teacher educators' abilities to use these pedagogies strategically and effectively.

Similar to our remarks about the content of science teacher education, we see numerous pedagogical possibilities as well—varied mentoring/induction practices, workshops, research experiences, and inquiry-based opportunities to study classroom practice. We also acknowledge that this list is incomplete; for instance, we have not discussed technology as a tool for science teacher education. While policies treat induction and mentoring generically, STEM ACT conference participants (along with other science education researchers) take a more nuanced approach; delineating specific practices and examining whether, and how, teachers benefit from those practices. Again, the research agenda STEM ACT participants advocate is not about selecting one pedagogical approach over another, but keeping the focus on teacher learning and broadening implications to include student outcomes as well.

6. Recommendations

In the preceding sections of this paper, we drew on STEM ACT research presentations and discussions to consider the question: "What do we know and what more do we need to learn about science teacher education that takes into account the results of more than 30 years of research on science teaching and learning?" We noted the teacher beliefs, knowledge, skills, and practices needed to support contemporary visions of science education. Moreover, we pointed out the wide range of content and pedagogies researchers explore as they examine science teacher education that supports reform visions. However, we state the obvious when we say that translating research on science teaching and learning into a variety of science teacher education settings is arduous work. There are multiple strands necessary. We need insight into (1) what kinds of learning opportunities support diverse learners' science engagement and understanding, (2) what science teachers need to learn in order to provide such opportunities for their students, and (3) what kinds of experiences teachers need to learn what they need. That is, if we want science teacher education to be research-based, then we need to have evidence that what and how we teach teachers benefits their students in meaningful ways.

While there have been ongoing research efforts in the three areas described above, there are also gaps, especially with regard to student learning. Moreover, these strands are often treated separately, rather than intertwined. In this section, we make recommendations for a research agenda that builds on existing research, keeps teacher and student learning central, and strengthens communication channels that support rigorous science teacher education research.

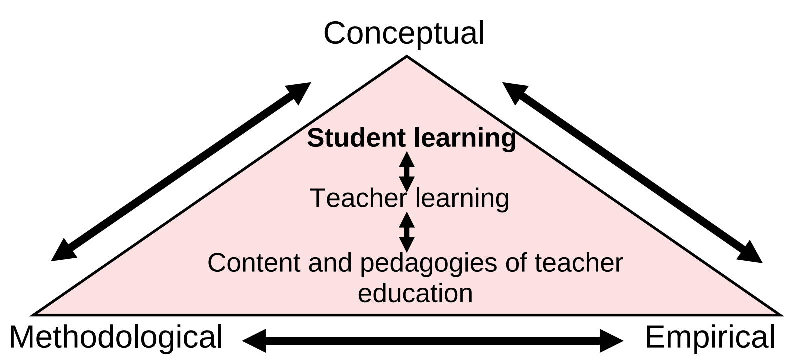

Figure 1. Research agenda for science teacher education

The work we have just described requires mutually reinforcing activity on three fronts – conceptual, methodological, and empirical (see Figure 1). We group our recommendations into these three broad categories, briefly describing each and including a few examples of some research questions generated during the STEM ACT research discussions.

One major conceptual issue that emerged from our discussions is the need for conceptual clarity (if not consensus) about what and how science teachers need to learn. We first noticed this with regard to alternative certification programs, but saw it in other places as well. Mentoring, inquiry and induction (just to name a few) are widely varied; researchers must be careful, for instance, about making broad claims about mentoring, without specifying the practices involved. Ongoing discussions about defining, and refining, research interests in useful ways for science teacher education would be a helpful step towards greater conceptual congruence.

Rigorous research not only requires conceptual clarity but methodological support as well. A research agenda focused on teacher and student learning requires robust tools for gauging change over time. Developing such measures demands substantial resources not available to many research teams. Investments in a pool of instruments to be shared across the science education research community regardless of program would facilitate cross-study comparisons. These shared measures would ideally include interview and classroom observation protocols, survey questionnaires, teacher assessments of content and pedagogical content knowledge, and student assessments.

The third focus for our recommendations relates to the need to develop empirical warrants for science teacher education practices with research that stretches across the teacher continuum and takes local contexts into account. For instance, there is an extensive line of research on students' science conceptions/ misconceptions/alternative conceptions. Several, more recent, studies of formative assessment examine how that information can assist teachers with their particular students' learning. We see here an example of an empirical chain that extends from science teacher education to student learning. However, this work means that as researchers, we must take a skeptical stance on what we hold dear. We cannot assume that our vision of science education reform "works" unless we have the evidence necessary to back it up.

We conclude our recommendations with a list of research questions proposed by STEM ACT research participants. This is not meant to be exhaustive; but to suggest potentially fruitful direction for ongoing science teacher education research.

7. Research Questions

- What science and in what form do science teachers need to know?
- How do we bridge traditional separations of preservice and inservice teacher education to create a professional continuum of science teacher education, which includes the induction phase?
- How do diverse teachers acquire the beliefs, knowledge and skills across a variety of educational settings and opportunities?
    - What *coursework* and *field experiences* lead to the development of knowledge and skills that help teachers, at various points in their professional development,

    bring reform visions into science classrooms (action research, institutional partnerships)?
  - What roles can *teacher collaboratives*—groups of science teachers learning together—play in the continued education and production of professional knowledge? (e.g. mentoring, communities of practice)
- Who are the science teacher candidates? How do the following relate to candidates learning to be science teachers?
  - Age, race, ethnicity, gender
  - Prior experience
  - Science knowledge
  - Context and societal influences
- How do we transform *credentialing* programs into research-informed *educational* programs?

Conclusion

Once the distinction between alternative and traditional programs is abandoned, we see that teacher education is a mix of coursework, fieldwork, and on-the-job learning experiences, each of which can vary in time and intensity. In this white paper we argue that what is needed, instead of comparisons of traditional and alternative certification programs, are studies that identify and examine how teacher learning occurs in those experiences; what is learned; and how teachers put that learning to use.

The research agenda outlined requires studies that cross the continuum of teacher learning experiences and that follow teachers longitudinally through their careers. In addition, studies are needed that examine the ways in which these experiences can be shaped to be part of teacher education programs that respond to the constraints and affordances of local situations. Research is also needed on subject matter and level specific teacher education and teacher learning that takes into account subject matter knowledge, pedagogical content knowledge, and content knowledge for teaching.

The research described is urgently needed to support science education reform. Amidst demands to improve science teaching, science teacher education is an essential reform tool. Consequently, our research in science teacher education needs to be as ambitious as our vision of science education reform. We cannot realize our potential without substantial investment in systematic conceptual, methodological, and empirical work.

Appendix: Research Presentations

The practice and policy presentations are listed in the respective reports. Abstracts and papers for most of these presentations are available at www.stemtec.org/act.

Keynote: *Ken Zeichner, University of Wisconsin-Madison*
Title: WHAT DO WE KNOW ABOUT THE CHARACTERISTICS OF GOOD TEACHER EDUCATION PROGRAMS?

Anita Greenwood, Kathy Shea & Charmaine Hickey, University of Massachusetts Lowell
Title: THE ROLE OF MENTORS AND COLLEGE SUPERVISORS IN PROVIDING INSTRUCTIONAL SUPPORT TO ALTERNATIVE ROUTE NOVICE STEM TEACHERS: TWO STUDIES

Carole Mitchener, University of Illinois at Chicago
Title: THE IMPORTANCE OF ACTION RESEARCH IN THE SECOND YEAR: LEARNING TO TEACH SCIENCE THROUGH AN ALTERNATIVE ROUTE

Jodie A. Galosy, Michigan State University
Title: A CASE STUDY OF AN URBAN DISTRICT: RESOURCES AND INTERN SCIENCE TEACHER’S CURRICULUM GOALS

Edward Britton, WestEd
Title: SUBJECT-SPECIFIC INDUCTION FOR BEGINNING SCIENCE TEACHERS

Daniel C. Humphrey, Marjorie E. Wechsler and Heather J. Hough, SRI International
Title: CHARACTERISTICS OF EFFECTIVE ALTERNATIVE TEACHER CERTIFICATION PROGRAMS

Joan Prival, National Science Foundation
Title: ALTERNATIVE CERTIFICATION MODELS: NSF FUNDING PPORTUNITIES FOR RESEARCH AND DEVELOPMENT

HsingChi A. Wang, University of Calgary, Canada
Title: UNFOLDING ISSUES OF SECONDARY SCIENCE TEACHER’S NOWLEDGE FOR AN ALTERNATIVE CERTIFICATION PROGRAM

Thomas R. Koballa Jr., University of Georgia
Leslie Upson Bradbury, Appalachian State University
Cynthia Minchew Deaton, University of Georgia
Shawn M. Glynn, University of Georgia
Title: CONCEPTIONS OF MENTORING AND MENTORING PRACTICE IN ALTERNATIVE SECONDARY SCIENCE TEACHER EDUCATION

Sandra Abell, Fran Arbaugh, Kathryn Chval, Patricia Friedricshen, John Lannin and Mark Volkmann. University of Missouri-Columbia
Title: RESEARCH ON ALTERNATIVE CERTIFICATION: WHERE DO WE GO FROM HERE?

Michele H. Lee, Travis A. Olson and Jay P. Scribner, University of Missouri – Columbia
Title: EXPLORING ALTERNATIVE TEACHER CERTIFICATION POLICY AND PRACTICE THROUGH AN EXAMINATION OF NOVICE SCIENCE TEACHERS

Posters

Abdulkadir Demir, University of Missouri, Columbia
Title: ALTERNATIVELY CERTIFIED BEGINNING SCIENCE TEACHERS' PRACTICE OF INQUIRY-BASED INSTRUCTION

Anne L. Kern and Gillian H. Roehrig, University of Minnesota
Julie A. Luft, Arizona State University
Title: EXAMINATION OF A SCIENCE TEACHER INTERN PROGRAM

Judith R. McDonald, Charlotte Mecklenburg Schools, NC
Title: A STUDY OF SECOND CAREER LATERAL ENTRY SCIENCE TEACHERS: THE RELATIONSHIP BETWEEN THE NATURE OF SCIENCE AND THEIR CLASSROOM PRACTICES

Donna R. Sterling, Wendy M. Frazier, Mollianne G. Logerwell and Anastasia Kitsantas
George Mason University
Title: NEW SCIENCE TEACHERS' SUPPORT NETWORK: HOW CAN WE HELP PROVISIONALLY LICENSED TEACHERS SUCCEED?

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