Building A Framework for Researching Teacher Change in ITEST Projects

A literature review produced by the

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February 2007

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Introduction

Information Technology Experiences for Students and Teachers (ITEST) provides access to cutting-edge technology to students traditionally underrepresented in the science, technology, engineering and mathematics (STEM) fields, and to the teachers who work with these students. The comprehensive projects work with teachers in intensive summer workshops and full-year ongoing follow-up to aid teachers in their implementation of varied and intensive technology experiences. After four years of project implementation, with 71 different projects around the country, we pause to reflect on the outcomes of the work. What does it look like when teachers implement ITEST project materials in their classroom? How do teachers change their practice to incorporate inquiry-based pedagogies? And most important, in this context, how can researchers effectively measure and describe both the changes in teacher practices and beliefs, and the outcomes for teaching and for student learning?

As a first step to answering these important questions, this review looks to literature on teacher change in science and technology education. We address the following question:

> *How do science and technology teacher professional development programs define and describe changes in teaching beliefs and practices that lead to the effective implementation of sophisticated science and technology into formal classroom teaching?*

We have organized this literature review by first considering the ways that teacher change has been conceptualized and studied in science and technology, then looking more carefully at the methods by which such research is carried out, and concluding with a proposed research agenda for ITEST projects. In the section looking at the conceptualization of teacher change, we begin with the goals of teacher change, address areas of complexity in teacher change such as the symbiotic relationship between changes in belief and changes in practice, and describe studies focusing on teacher change in four areas: knowledge/beliefs, technology integration, inquiry practices, and understanding learners. We then shift to a focus on the methodological challenges of measuring teacher change, including: the research tension of attempting to measure change processes that can take years to manifest themselves within programs with clear time constraints; the difficulties of relying on teacher self-assessments for measuring changes in both practices and beliefs; and the difficulty of arriving at a common, and measurable, definition of inquiry learning. We conclude the review by identifying three ways in which ITEST projects are uniquely situated to address gaps in the current research:

- conducting longitudinal studies to trace change over time;
- studying cutting edge technologies in the middle and high school context; and
- studying the impact of teacher change and access to cutting edge technologies with underrepresented students.

Teacher change in science and technology

This review looks at teacher change processes for both science education and technology integration. Professional development for science education has a long history, and practitioners and researchers have refined a number of different frameworks for program development (Loucks-Horsley, Hewson, Love, & Stiles, 1998). Technology, on the other hand, is a newer field, and thus has fewer established frameworks. In addition, because of the rapid changes in technology, the relatively new field has already experienced at least two different "generations" of technology professional development. Much of the technology research in the 1980s and 1990s focused on technology integration in schools, and the challenges of getting teachers to incorporate computers into their teaching. This is gradually changing, as more and more US schools improve their technology infrastructure, and as teachers gain more technology knowledge. According to Ertmer (2005), "the foundations for effective technology integration finally appear to be in place" (Ertmer, 2005, p. 36). Four elements have emerged as critical to successful technology integration: teachers must have convenient access; they must have adequate preparation; they must have some freedom in the curriculum; and their curriculum beliefs need to be aligned with constructivist pedagogy (Becker, 2000, in Ertmer, 2005; Vrasidas & Glass, 2005). With many of these elements in place in many schools, technology professional development is shifting into a "second generation" of integration of more sophisticated, student-centered technologies. Science and technology education share a critical element, one which continues to be elusive for professional developers and researchers alike: fostering profound changes in teacher beliefs and practices, in order to take full advantage of the potential for student learning.

Why teacher change?

The overall goal of any professional development process and/or program seeking to change teacher beliefs and behavior is to improve student learning, interest, and motivation; what has been termed "developing the best means to reach all students" (Loucks-Horsley et al., 1998, p. xviii).

> The new vision of mathematics and science teaching is one in which all students engage in inquiry into significant questions in science and mathematics in supportive, collegial communities. To achieve this vision, teachers need new knowledge, skills, behaviors, and dispositions. They need to have ownership in the new vision and feel competent and comfortable to create appropriate learning environments for their students. This includes feeling secure in their knowledge of the content they will help their students learn.
>
> (Loucks-Horsley et al., 1998, p. 1)

In general, teacher change is initiated, promoted, and supported through professional development programs. Some programs identify specific changes in teacher practices that they look for, such as asking conceptual change questions, developing interdisciplinary projects, enhancing teachers' techniques for fostering inquiry, problem-solving, and cooperative learning, or providing collaboration opportunities for teachers (Basista, Tomlin, Pennington, & Pugh, 2001; Tal, Dori, & Keiny, 2001; Yip, 2004). Others describe looking for shifts in teacher practice to facilitation rather than frontal teaching and the use of more varied pedagogical strategies, including constructivist, student-centered teaching methodologies (*Educating Teachers*, 2001; Vrasidas & Glass, 2005).

A second set of goals for many professional development programs focuses on content acquisition, including acquiring deep content knowledge, increasing professional efficacy, understanding student learners, establishing clear learning goals, and addressing student misunderstandings (Basista et al., 2001; *Educating Teachers*, 2001). When considering the potential changes to teaching practices presented by sophisticated technology, Linn (2003) identifies a new series of goals for professional development programs to consider, including: providing tools for teachers to use new technologies, and increasing their science and their technology literacy; for example, by “infusing projects into science learning” (Linn, 2003, p. 754).

How does change happen?

There are many different theories about how change occurs in teacher practice, especially when considering technology integration. Rogers (1995) describes a series of stages, ranging from passive knowledge to confirmation of technology use, when teachers leverage technology to engage students in tasks that involve organizational skills and the ability to master content and apply basic skills, they develop new applications for technology use, and collaborate with other teachers to create unified technology use across the curriculum. Though Rogers developed his theory in 1995, and technology has advanced rapidly since then, his framework remains applicable. Shuldman (2004) developed a model of technology integration by joining together a number of frameworks, including Innovation Diffusion (Rogers, 1995), the Concerned Based Adoption Model (Hall & Hord, 1987, in Shuldman, 2004), Apple Classrooms of Tomorrow (Sandholtz, Ringstaff, & Dwyer, 1997, in Shuldman, 2004), Instructional Transformation (Hooper & Rieber, 1995, in Shuldman, 2004), and Learning/Adoption Trajectory (Sherry, 1998, in Shuldman, 2004). Rather than advocating one model over another, Shuldman uses elements of each of them to describe a continuum of knowledge and skills from naïve (compatible) to sophisticated (transformative). He highlights the importance of the middle part of the continuum, when teachers shift from experimentation to consistent use, because the transition indicates a milestone or turning point in technology integration (Shuldman, 2004). Rogers called this the “decision stage,” when teachers choose to accept or reject new changes and begin to see ways technology might be connected to the curriculum (Rogers, 1995).

Change occurs in stages, and it is not always clear whether shifts in belief precede shifts in practice, or vice versa. Guskey argues that "Change in beliefs follows, rather than precedes, practice" (Guskey, 1986). Evidence has not always supported that assertion, however, and the question of whether changes in deep-seated teacher beliefs are an essential prerequisite to changes in practice continues to occupy the time of both researchers and practitioners. Ertmer suggests that technology integration projects should focus on both beliefs and practice, because it is not clear which one precedes the other, and in fact, it may be that in some situations beliefs are the first to change, while in other situations practice changes first (Ertmer, 2005).

The relationship between beliefs and practice may depend on teacher type. Novice teachers can change attitudes first because they don’t have so much built-up experience, but they are too new at teaching to change their practices as quickly as veteran teachers can. On the other hand, veterans can change their practices, but won’t change their beliefs until feedback from their students over time proves to them that the change was worth it. Baumfield (2006) calls this “positive dissonance” when students surpass teachers’ expectations and teachers add more student-centered methods in response.

Professional development for teacher change

Structures of professional development

Isolated workshops and conferences do not have a lasting impact on practice, and so the emphasis has changed to ongoing professional development (*Educating Teachers,* 2001). Effective professional development requires time (Duschl, Schweingruber, & Shouse, 2006). Some researchers argue that up to 80 hours of professional development, spread out over an extended period, is the most effective way to sustain teacher change (Basista et al., 2001; Mouza, 2005). Follow-up to initial professional development institutes is critical, and the follow-up must respond to different teacher needs. Teachers take advantage of the follow-up opportunities that work for them (Luft, 2001). When the expectations for change are greater, teachers need more support, and the professional development structure needs to account for that (*Educating Teachers*, 2001).

Pedagogical elements of professional development

Effective professional development involves teachers in "doing" science, mathematics, and technology. This means that technology itself is integrated into the professional development process (Vrasidas & Glass, 2005). This process of immersion is the first step to helping teachers integrate technology into their personal teaching methods. Only once the technology is fully integrated can it become an effective tool for educating students (Goddard, 2002)

Effective professional development imitates the kinds of teaching that it promotes. If the professional development focuses on using inquiry methods in the classroom, then teachers use inquiry as part of their professional development activities (Basista et al., 2001). This helps teachers to become learners as they "do," and as they experience the actual learning experiences and materials they will use with students (Loucks-Horsley & Matsumoto, 1999; Peck, Barton, & Klump, 2007). This can be challenging and frustrating, as teachers experience the challenges that students face, or as everyone together struggles to come to a clear definition of inquiry-based teaching.

Building a community of practice

In the field of professional development, one of the basic tenets of good practice is that professional development has to be integrated into teaching practice. Within schools, teachers are increasingly encouraged to work in collaborative teams, to share student work with each other, and to view their teaching practice within a broader context than just the classroom. In addition, good professional development promotes networks across school boundaries, including partnerships with scientists and mathematicians, and coaching and mentoring for both teachers and students (Davis, Petish, & Smithey, 2006; Loucks-Horsley & Matsumoto, 1999). There is a critical need to build partnerships between universities, schools, and technology experts, which can become communities of practice (Vrasidas & Glass, 2005).

Context in teacher change

Professional development does not take place in a vacuum. Rather, teachers work within the context of their own lives and personal experiences, within the school and district culture, and within the broader community. There are contextual conditions that need to be in place to ensure successful implementation of changes in teaching, including availability of resources, dissatisfaction with the status quo, existence of knowledge and skills, availability of time, rewards or incentives, participation, commitment, and leadership (Shuldman, 2004, p. 325).

Teacher background and experiences

Many different characteristics of teachers can have an impact on their change process. Their initial comfort with the concepts being presented (both content and pedagogy), their current teaching practices, and their previous professional development experiences, play a role in their willingness to participate actively in professional development (Astor-Jack, Balcerzak, & McCallie, 2006; Loucks-Horsley et al., 1998). The culture of schooling is important in all change processes, and when the change focuses on technology integration, the culture of computer use must also be considered (Mouza, 2005). In addition, the technology target is fluid, as rapid changes in technology and increasing comfort among new teachers contributes to the shift in favor of comfort with technology. In contexts where teachers are generally comfortable with basic technology use, the introduction of more sophisticated technologies can be more successful.

Teachers can be classified by years of teaching experience, as novice, experienced, and veteran teachers (Barnett, Keating, Harwood, & Saam, 2002; Watts, 2005), and each level of teaching experience has its 'culture.' Grade-level of the science teachers' students is also an important factor. Studies of elementary teachers' experiences mentioned that the teachers frequently had a fear of teaching science and that the scientific knowledge of K-8 teachers is weak (Duschl et al., 2006; Jarvis & Pell, 2004; Lee, Hart, Cuevas, & Enders, 2004). Luft (2001) found that pre-service and new teachers were more likely to change their beliefs, while experienced teachers were more likely to change their instructional practices to include inquiry. Some studies classify teachers based on their willingness to adopt a new teaching practice, e.g. Songer, Lee, & McDonald's "maverick teachers" (2003). Jarvis & Pell (2004) found that students' cognition and attitudes varied more due to teacher type than due to whether their teachers participated in the professional development program. The teacher types they identified were: disaffected, low cognitive levels, enthusiastic, and unaffected. Luft (2001) found that teachers differed by the types of follow-up activities they preferred and utilized. Varying levels of comfort, often with respect to technology or managing student-centered classroom activities, also emerged in studies (Astor-Jack et al., 2006; Barnett et al., 2002).

Thus, teacher context can refer to years of teaching experience, previous background, grade level, teacher type, or any combination of these. Research studies need to take teacher context into account in the design and implementation of any study of teacher change.

School, district and national context

Teachers, though they may teach alone in a classroom (and even this is less and less the case), have to account for many different stakeholders and factors in their teaching. Teachers work within a school context, a district context, as well as a state and national context. Depth and duration of change, whether in beliefs or practice or both, depends on all of these contexts. All aspects of teaching, from pedagogy to the curriculum are a result both of teacher preference and of social, cultural, historical, and economic needs of the time (Goddard, 2002).

Administrators, both at the building and at the district level, can be crucial to the successful implementation of technology change through their leadership, knowledge, and skills (Shuldman, 2004). School administrators, especially principals, are instrumental in setting the tone for continuous review and improvement, maintaining high expectations, providing financial resources and support for professional development, and contributing to the organizational culture of each school (Loucks-Horsley et al., 1998; Mouza, 2002; Peck et al., 2007). Their views of the conditions necessary to promote technology are instrumental in putting those conditions in place. While teachers are the focus of professional development, they are part of a wider education network, and principals and other administrators are critical to supporting effective change (Basista et al., 2001).

Local, state, and national policies also must be accounted for when describing the context within which teachers teach (Loucks-Horsley et al., 1998; Mouza, 2005). As much as possible, professional development should be part of a coherent instructional system – connecting the dots between content and performance standards, instructional materials, local/state assessments, school/district goals, and the development of a community of learners (Duschl et al., 2006). In a multiyear study of the Kids as Global Scientists (KGS) program, researchers created a composite description of what distinguished urban teachers who participated from their (largely suburban) counterparts—larger class sizes, unreliable Internet access, and higher percentages of students who are not native English speakers, for example (Songer et al., 2003).

Particular obstacles emerge when looking at technology integration, many of which have been described and addressed in other parts of this paper: the conservative nature of the traditional culture of schooling and classroom instruction; teachers' resistance to changing their traditional teaching approaches; lack of time for teachers to learn how to use and integrate technology in their teaching; lack of technology infrastructure; lack of specific technologies that address the specific needs of teachers and students; lack of ongoing support; lack of release time and incentives for teacher innovators; incompatibility of frontal teaching with the constructivist framework fostered by technology; need for teachers to unlearn certain teaching beliefs and practices; need to prepare teachers to integrate technology in the classroom by integrating similar technology in teacher preparation programs; and need for policy, curriculum, and assessment reform (Vrasidas & Glass, 2005).

In addition to accounting for all of the different contextual issues facing teachers, other challenges to consider include ensuring equity, building professional culture, developing leadership, scaling up, garnering public support, supporting standards, evaluating professional development, and finding time for professional development (Loucks-Horsley et al., 1998; Mouza, 2002; Peck et al., 2007; Shuldman, 2004; Songer et al., 2003).

Studies of teacher change

While there is no single theory of teacher change that explains the complicated change process, and while the relationship between beliefs and practices continues to be complex and nonlinear, researchers and practitioners have used existing knowledge to develop concrete professional development programs geared to promote change that will result in the pedagogical and content shifts which will increase student learning. Studies examining changes in teacher use of inquiry-based science teaching after participating in professional development programs generally have several points in common: the professional development programs were designed based on widely recognized principles of effective professional development, often those described by Loucks-Horsley (1998), and reference national science standards (*National Research Council*, 1995). The teachers participate in an intensive session (often a summer institute) and implement what they learn during the following academic year supported by follow-up and support from the professional development organizers. For science teachers, professional development with this general structure can be seen literally as a response to their requests. When teachers were involved in the very beginnings of planning at the Institute for Inquiry in Texas, they asked the Institute to provide "science and math content wrapped in the context of meaningful, inquiry-based explorations aligned with national and state standards"(Kelly & Weis, 2005, p. 46).

The studies and the programs described here vary widely in their focus. They focus on different student populations with different levels of involvement, they include different levels of participation of college faculty, administrative support from the teachers' home districts or schools differs widely, and technology use patterns and the types of follow-up offered are quite varied. Depending on the study purposes and context, different aspects of teacher change are measured. In this literature review, we have divided them into four areas: content knowledge, skills and beliefs; technology skills; inquiry/pedagogy, and understanding the learner.

Teacher content knowledge, skills, and beliefs

It almost goes without saying that good professional development includes quality content (Astor-Jack et al., 2006; Duschl et al., 2006; Mouza, 2005). Professional development in the sciences covers rigorous science content, while technology professional development includes technology content (Loucks-Horsley et al., 1998). Rigorous science content includes "the major concepts, assumptions, debates, processes of inquiry, and ways of knowing that are central" to the science discipline (*Model standards in science*, 1992, as cited in Davis et al., 2006, p. 613). When professional development targets the integration of technology into science teaching, it shows how technology can support the learning process in scientific inquiry, rather than direct it (Goddard, 2002). This model of teacher change leads toward constructivist methods of teaching (Vrasidas & Glass, 2005).

Jarvis & Pell (2004) studied the effects that a standards-based constructivist in-service training had on primary teachers' confidence, beliefs, and science understanding. They found that after the in-service, the teachers did change their classroom practices to reflect the new techniques they learned. However, these changes weren't necessarily driven by shifts in the teachers' underlying pedagogical beliefs—as measured by pre/post assessments, the teachers' beliefs remained relatively stable six months to one year after participating. Researchers speculated that the time frame was perhaps not long enough for teachers to see consistent benefits and to change their beliefs accordingly. For the students, changes in teacher techniques were enough to yield positive results. Students of teachers who participated in the in-service exhibited greater engagement with science than their control-group peers.

Elementary teachers described in Lee et al. (2004) reported reduced fear of teaching science after participating in the professional development program under study. They also used more scientific vocabulary during their daily lessons. The investigators tie content knowledge to inquiry, noting that teachers' instructional practices vary with their perceived level of mastery over the content. Teachers who are more confident in their subject-matter knowledge are more willing to adopt student-centered instructional methods (Carlsen, 1991; Smith & Neale, 1989, as cited by Lee et al., 2004, pp. 1037-1038).

In contrast, changes in attitude seemed to come first for teachers in a joint Georgia-Florida professional development program (Gordon, Gerber, & Price, 2002). The teachers integrated more and more technology and inquiry into their lessons in response to noticeable improvements in student enthusiasm and learning. To explain the teachers' change process, researchers looked to van den Berg (2001, as cited in Gordon et al., 2002) who stated that teacher change happens (or does not happen) based on three considerations: whether the implementation requirements of the new method are clear, whether the new method is aligned with the teachers' beliefs, and whether implementing the new method is likely to produce results beneficial enough to justify itself.

In general, studies found that teachers' knowledge of science content, their skill in implementing inquiry pedagogy and their confidence in the knowledge and skills were intimately linked to their attitudes and beliefs about science teaching, inquiry, and their expectations for students. Participation in these professional development programs led to teacher gains in content knowledge, professional efficacy, and understanding of the inquiry process (Basista et al., 2001; Jeanpierre, Oberhauser, & Freeman, 2005; Luft, 2001; Watts, 2005). Gordon et al. (2002) sum up the general consensus when they state, "Teachers can and will change the way they think about and do science" but they require professional development support to do so (Gordon et al., 2002, p. 11).

Technology skills

Inquiry-based instruction and technology integration can be successfully paired in teacher professional development (Barnett et al., 2002; Beglau, 2005; Krajcik, Blumenfeld, Marx, & Soloway, 2000). Irving (2006) describes two ways of incorporating technology in the classroom: learning from technology through information delivery, and learning with technology through knowledge construction. The 'first generation' of research on technology focused on information delivery, while the 'second generation' focuses on knowledge construction, and encourages inquiry learning.

> Although inquiry can be done in classrooms without the aid of technology, learning technologies expand the range of questions that can be investigated, the types of information that can be collected, the kinds of data representations that can be displayed, and the products that students can create to demonstrate their understandings.
>
> (Krajcik et al., 2000, p. 293)

"First generation" technology integration

Early studies of technology integration in classrooms focused on the teachers' use of computers. This usage by teachers primarily supported their abilities to make their work more efficient. In this context, teachers used computers to create or maintain administrative records, communicate with colleagues or parents, or research or develop lesson plans and classroom materials. As the use of the computer became more prevalent and teachers' experiences with technology grew, researchers began to document the ways in which the use of the computer and related technologies were integrated in classroom instruction.

One of the early, large-scale efforts to integrate the use of computers in the classroom was an initiative supported by Apple Computers, Inc. Between 1985 and 1998, the Apple Classrooms of Tomorrow program provided teachers and students in more than one-hundred classrooms across the United States with computers for use both in school and at home. Various researchers have referenced this initiative to highlight the importance of access to resources, the role of teachers' attitudes and beliefs, and the need for time for constructivist methods to emerge in teaching (Barron, Kemker, Harmes, & Kalaydjian, 2003; Dexter, Anderson, & Becker, 1999; Ertmer, 2005; Ertmer, Addison, Lane, Ross, & Woods, 1999).

Other research on teachers' use of computers to facilitate classroom instruction have focused generally on the actual use of this technology and additionally on issues related to educators' beliefs and attitudes, teaching practices, or student learning. Focusing principally on implementation, many of these studies show a relatively narrow range of applications. Ertmer et al. (1999) demonstrated that teachers' use of technology in elementary classrooms was used to extend teacher-centered practices through instructional games or informational CDs. The study noted that use of the computer ranged from infrequent to daily, and that the majority of uses were within the context of a learning station where students gathered around the computer station to participate in content- or skill-related learning experiences (Ertmer et al., 1999). Ertmer et al. (1999) additionally examined the relationship between teachers' barriers to technology implementation and their values and beliefs regarding integration and classroom practice; the findings suggested that adequate training and resources as well as opportunities to learn from peers would help address the barriers that teachers encounter.

Using several measures of technology integration established by the National Educational Technology Standards for Students, Barron et al. (2003) investigated the extent to which computers were integrated into classroom practice in the following areas: productivity, communication, research, and problem solving (Barron et al., 2003). The research showed that compared to high school teachers, elementary school teachers were twice as likely to use computers as a problem-solving or communication tool. One explanation for this occurrence may be that elementary level teachers have a greater degree of flexibility over their classroom schedule. The research also indicated that science teachers were more likely than math or English teachers to integrate computers as a research tool.

Another study focused on several areas of teachers' use as well as teacher-directed student use of technology in the classroom (Bebell, Russell, & O'Dwyer, 2004). The research showed that teachers' use was mostly concentrated on administrative purposes like class preparation, professional email, and grading. There were distinctions, however, between more and less experienced teachers; new teachers were more likely to use computers for preparation and accommodation (e.g., adapting materials to meet a student's individuals needs, preparing or maintaining an IEP), and were less likely to employ technology for student use during class. Bebell et al. (2004) also found that elementary teachers were more likely to use computers for preparation and student use during class while middle and high school teachers were more likely to use this technology for preparation and grading.

A case study of four Canadian schools examined the factors contributing to teachers' successful integration of technology (Granger, Morbey, Lotherington, Owston, & Wideman, 2002). The teachers in the schools that they investigated utilized computers – in either a classroom setting or in a computer lab – for internet research, email communication, library instruction, or students' writing and editing skills. Granger et al. (2002) reported among their findings that teachers' range in technology experience or familiarity represented an obstacle to collective staff development. Additionally, the research showed that the teachers were able to identify concrete strategies to help remove these obstacles, including training, collaboration with colleagues, and positive advocacy by school personnel (e.g., principals).

The prevalence of research on lower-level versus higher-level integration is a matter of the evolving nature of educational practices as well as one related to support (available professional development and infrastructure) and experience. Although many teachers are using technology for lower-level tasks, higher-level uses are still in the minority, primarily because low-level technology uses are associated with teacher-centered practices, while high-level uses are associated with student or constructivist practices (Ertmer et al., 1999). Furthermore, the use of computers in the classroom for word processing, multimedia authoring, digital information sources, and the internet does not substantially alter the teachers' approach to instruction; rather, the actual teaching experiences, the opportunity to reflect, and the professional culture of the school influences the knowledge-construction process (Dexter et al., 1999).

"Second generation" technology integration

Studies of higher-level technologies are focused not only on advanced technologies, but also on evolving approaches to teaching and learning. These studies have a greater concentration on student-centered, rather than teacher-centered, pedagogical methods. Since the integration of higher-level technologies in the classroom is an emerging area, there is a smaller collection of research in this area.

Computer and video games are a new technology that teachers are using with their students in a number of contexts. Quest Atlantis, a computer game that engages students ages nine to twelve years to embark on quests to save an alternative universe, combines learning with education, entertainment, and social awareness (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005). Implemented in dozens of elementary school classrooms and a couple of after-school sites, Quest Atlantis moves away from a model of knowledge transmission – either through texts or lectures –toward a paradigm that uses experiential learning, inquiry-based learning, and portfolio assessment. While Barab, et al. (2005) note successful implementation, its early use may be the reason that they do not note specific teacher or student outcomes.

Lego® models are another tool that teachers have used in their science instruction. A study by Rothhaar, Pittendrigh, & Orvis (2006) examined the use of the Lego® Analogy Model (LAM) to teach gene sequencing and biotechnology using a curriculum called the Genomic Analogy Model for Educators (GAME). The three main components of the GAME program consisted of a CD-Rom, a website, and lab exercises. The use of Lego® structures provided students' with hands-on experiences. Rothhaar, Pittendrigh, & Orvis (2006) reported an increase in high school students' knowledge of genomics and biotechnology. The short term effect of the curriculum did not, however, yield a significant change in students' attitudes towards genomics and biotechnology. It was noted that the brief duration was not sufficient time to measure changes in attitudes.

Gerber (2003) found that Learning through Inquiry Science and Technology (LIST) increased rural teachers' awareness and classroom use of inquiry and technology. For the LIST teachers, having the professional development sessions on-site at their schools greatly increased their confidence in integrating technology into lessons because the professional development activities used the hardware and software that was available to them during the academic year. Other programs tailor the technology aspect of teachers' professional development by building options into the system such as different modes of delivery depending on technology access. Songer et al. (2003) studied Kids as Global Scientists (KGS), an inquiry-based middle school learning environment. In their comparison of successful classroom implementations, they note that when students had access to the Internet, they could take part in live discussion forums with other students and with meteorologists. However, if the Internet connection was unreliable or unavailable, then the teachers could guide the students to materials on CD, including archived discussions. Having this rich back-up source of data made integration of KGS possible for the teachers.

Other research shows that the use of technology combined with specific teaching methods yield positive results. A three-year study of Israeli high school students enrolled in an Electricity track for low-achieving students showed that the combination of technology and project-based learning contributed to the students' success (Doppelt, 2003). The use of computerized technological systems put students in control of designs and experiments, and allowed them to work on projects they cared about personally. As Doppelt (2003) indicated, the experience of project-based learning further encourages students to explore new areas, discover new scientific issues, and integrate knowledge from different subjects. The teachers received additional in-service training in project-based learning to help them apply alternative methods for teaching and learning. The students also were enrolled in summer camp, which allowed them additional opportunities beyond the typical high school experience.

As technologies have advanced, there are increasingly new roles for their integration into the classroom. While lower-level technologies may have offered specific uses, new technologies allow teachers to expand upon their applications. Linn (2003) provides several examples of different ways to improve traditional methods. The conventional use of science texts and lectures by teachers to transmit information to students can be enhanced in a number of ways, and researchers have documented various successes and challenges. One starting point is to offer on-line versions of science textbooks (Linn, 2003), although Linn also found that including the use of hypertext to promote further investigation caused confusion among users. A number of tools to allow students to keep a history of materials, bookmark related items, map relationships, or create notes along the way have been tailored to ease students learning. Other opportunities to improve upon existing technologies and simultaneously put the student at the center of learning include online collaboration, internet data collection, models and simulations, and science visualization (Linn, 2003). Internet sites that provide data sets, graphing programs or simulated resources provide opportunities for students to use technology for inquiry (Irving, 2006).

While making a case for using Internet-based GIS in schools, Baker (2005) notes that even though the Internet-based GIS requires less user training than its desktop software counterpart, teachers need explicit training on integrating the technology into lessons. This caution is supported by Park, Ertmer, & Cramer's 2004 study of teachers who implemented technology-enhanced Problem Based Learning in their classrooms; learning to use new hardware and software during professional development was not sufficient to give teachers confidence that they could use the tools with their students in meaningful ways. When teaching teachers to use technology in classrooms, the technology exercises can't be busy work. The technology must demonstrate that its use can lead to teaching outcomes not possible with traditional teaching methods (Barnett et al., 2002).

A review of the literature on studies of higher-level technologies in the classroom reveals that there are many areas that have yet to be examined. Most research looking at the impact of technology programs has been done at the post-secondary level (Deadman, Hall, Bain, Elliot, & Dudycha, 2000; Mayer, Mautone, & Prothero, 2002; Moreno & Mayer, 2002, 2005; Turbak & Berg, 2002). Internet-based videos allowed students in university education methods courses to view real teachers conducting real inquiry-based lessons without the scheduling hassles of visiting classrooms (Barnett et al., 2002). Because the students viewed the same videos, they had common reference points during online discussions, and instructors were able to expose the students to different teachers' varying strengths and weaknesses in leading inquiry-instruction. Robotics, geographic information system (GIS) mapping, and multimedia gaming, are gradually emerging at the middle and high school levels, but to date there are only descriptive studies of how these technologies have been implemented in the classroom (Coslow, 2006; Drennon, 2005; Sanders Jr, Kajs, & Crawford, 2001), without any analysis of outcomes or challenges that teachers and students face.

Inquiry/instruction

Professional development programs inevitably address pedagogical methods, but there is little agreement on how to define those methods. In a review of studies on new and pre-service science teachers, Davis (2006) found that new teachers tend to teach less from reform-oriented science than is anticipated, and that they have more sophisticated ideas about instruction than they are able to actually practice.

Repeatedly, in studies looking at both science education and technology integration, researchers describe efforts to implement inquiry-based learning. However, the definition of inquiry-based learning varies from study to study, and from professional development program to professional development program (Minner, 2007). Inquiry-based learning is not a single strategy, but rather a way of thinking about learning that can be implemented in different ways.

> Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. Students will engage in selected aspects of inquiry as they learn the scientific way of knowing the natural world, but they also should develop the capacity to conduct complete inquiries.
>
> (*National Research Council*, 1995)

Songer et al. (2003) take issue with interpretations of the inquiry standard in the NRC, saying that people's conception of inquiry is too narrow, that classroom observers may dismiss legitimate demonstrations of students' higher-order thinking skills during an inquiry investigation if the classroom organization does not match the observers' preconceived ideas of what logistics and processes are conducive to inquiry. By comparing urban and suburban/rural classrooms whose students successfully completed inquiry activities, they point to differences in the teachers' classroom management and style. For example, the urban teachers tended to use minimal small group work, while suburban classrooms use more. The authors call for more research about inquiry-learning and diverse students. Jeanpierre, Oberhauser, & Freeman (2005) describe two levels of inquiry: full inquiry, where students choose questions, pursue the questions, and complete projects with research findings. They contrast this with the classroom activities of teachers "almost doing inquiry," that is, using parts of the scientific process, but not going through all the steps in every investigation. At the same time, misunderstandings about inquiry can lead teachers to define a teacher-directed hands-on activity as "inquiry" (Luft, 2001). In this literature review, we do not use a single definition of inquiry, but accept the definitions used in each study.

Teachers are not the only ones with varying definitions of inquiry. Astor-Jack (2006) investigated the professional development programs of four informal science centers and found that the centers differed on whether they defined "inquiry" as a teaching strategy or a learning strategy. The same study cautions that, just as teacher comfort with technological and scientific content must by taken into account when planning professional development, so does the center staff's comfort with inquiry-based pedagogy.

Despite the varied definitions of inquiry learning, researchers continue to use the term, and to measure change based on their own definitions of the term. Teachers who completed an inquiry-based science and math program that modeled inquiry and cooperative teaching methods (and also included an inquiry-awareness workshop for administrators) reported increased knowledge and professional efficacy (Basista et al., 2001). Students of teachers participating in inquiry-based professional development exhibited increased engagement in science (Jarvis & Pell, 2004; Gordon, Gerber, & Price, 2002). Whether or not they incorporated inquiry into their teaching after professional development programs, teachers in reviewed studies improved their working definitions of inquiry (Barnett et al., 2002; Huber & Moore, 2001; Kelly & Weis, 2005). For example, Luft (2001) reports that after the professional development sessions, teachers no longer mentioned activities that were hands-on but closed-ended when asked for examples of ways they used inquiry in their classrooms.

Most importantly, professional development around inquiry does lead to increased inquiry-based teaching in classrooms (Gerber, Price, Barnes, Hinkle, Barnes, Gordon, & Stanley, 2003; Huber & Moore, 2001; Jarvis & Pell, 2004; Jeanpierre et al., 2005; Luft, 2001). After introducing teachers and students to authentic scientific research through Monarch butterfly ecology, Jeanpierre et al. (2005) attributed teachers' successful implementation of classroom inquiry to the following program components: "deep science content and process knowledge with numerous opportunities for practice; the requirement that teachers demonstrate competence in a tangible and assessable way; and providers with high expectations for learning and the capability to facilitate multifaceted inquiry experiences" (Jeanpierre et al., 2005, p. 682). High expectations for teachers led to teachers having higher expectations for their students as students demonstrated they were capable of doing the research. One vehicle for the reinforcement of the high expectations the program held for its participants was the requirement that teachers and students write up their research findings. Watts (2005) had success with a similar requirement; teacher's confidence increased after presenting their research in a public symposium after the professional development institute.

Project-based learning, hands-on, and other teaching strategies

Some teachers changed their teaching practices as a result of professional development programs but for various reasons, stopped short of implementing inquiry-based lessons. For example, teachers who did not conduct full cycles of the Search, Solve, Create, and Share (SSCS) problem solving model did add instructional methods such as cooperative grouping or having the students collect data (Luft, 2001).

Huber & Moore (2001) suggest guidelines for expanding existing hands-on activities described in curriculum materials so that they are no longer step-by-step cookbook exercises but actually inquiry-based. The authors say that "an ideal activity for hands-on, inquiry-based instruction focuses on the science content students are learning" (Deal, 1994; *National Research Council*, 1995, as cited in Huber & Moore, 2001, p. 34).

Teachers need to understand learners, including their own learning

In addition to content knowledge, good professional development also includes providing knowledge of learners and learning, teachers and teaching (Mouza, 2005). Teachers need to know more about how students learn and develop, including the diversity of learning styles (Davis et al., 2006). Davis found that new teachers do not have clear ideas about how to incorporate students' ideas or backgrounds into their teaching, though they recognize that it is important (Davis et al., 2006). There is consensus that diverse populations bring distinct experiences and identities to the learning experience, but little agreement on the most effective means of teaching diverse populations. Studies show that giving teachers opportunities to learn a range of strategies helps improve practice and student learning (Duschl et al., 2006). At the same time, teachers' understanding of how students learn contributes to how they structure the classroom learning environment, and their instructional decisions over time (Duschl et al., 2006).

Technology advances mean that teachers must provide students with the knowledge and skills needed to lead productive lives, which include the ability to use technology (Goddard, 2002). At the same time, youth, when provided with basic access to technology, often jump light years ahead of their adult teachers (Barron, 2005; Guterl, 2003; Papert, 1998; Ryberg, 2004; Tapscott, 1998; Turkle, 1997). Youth ease with technology has the potential to fundamentally shift the nature of relationships in the classroom (Tapscott, 1998), although studies also indicate that while youth are facile with certain aspects of technology, they can still benefit from the facilitation of appropriately prepared teachers.

Both teachers and professional development providers can benefit from understanding more about the adult learning and change process (Loucks-Horsley et al., 1998). This helps them to become reflective practitioners who are better able to evaluate the effect of choices/actions on students, parents, and other professionals, and one who actively seeks opportunities to develop professionally (Davis et al., 2006).

Inquiry-based instruction for diverse students

One glaring gap in the literature is the scarcity of studies examining teachers' use of inquiry-based instruction with students from diverse backgrounds. Some studies mention that a goal of their professional development session is to ensure equitable STEM opportunities for diverse students, but don't elaborate with specific recommendations, suggesting that the equity goal is met simply by working with teachers who teach students of color or students from socioeconomically-disadvantaged families or English language learners (ELLs) (Basista et al., 2001; Gordon et al., 2002; Luft, 2001). Baumfield (2006) reports that teacher use of Thinking Skills Approach (increased and strategic use of open-ended questioning) is effective in gifted and talented programs, with students with learning disabilities, and in mixed classrooms. Beglau (2005) found that enrollment in a classroom where the teacher used Missouri's Instructional Networked Teaching Strategies (eMINTS) reduced standardized score differences attributable to low socioeconomic status and enrollment in special education. Black students in eMINTS classrooms also tested higher than their peers in non-eMINTS classrooms, although the sample size was small (Beglau, 2005).

However, studies that do focus on the effectiveness of inquiry-based teaching techniques for students from diverse backgrounds can go beyond confirming that inquiry-based instruction can be successful with all kinds of students; some studies are turning up some intriguing and unexpected findings. Teachers implementing inquiry-based science lessons in classrooms with high percentages of ELLs (Lee et al., 2004) found that an inquiry approach allowed the students to demonstrate knowledge in multiple ways (i.e. oral and/or graphical methods—written English was not the only option). The teachers, therefore, were better able to assess students' learning. When comparing classrooms in which successful inquiry had taken place, Songer et al. (2003) found that classroom structures that led to student use of higher-order thinking skills in urban schools were not necessarily the same as those that were traditionally used in suburban schools. Urban teachers tended not to use small-group work, for example. The authors stress that the quality of student's intellectual engagement should be the deciding factor when determining whether inquiry is occurring in a classroom, and they call for more research into multiple models of classroom-based inquiry and the longitudinal development of inquiry thinking in young people.

Teachers' appreciation and understanding of student diversity has consequences for instruction (Duschl et al., 2006), but this is rarely addressed in science or technology-focused professional development. Many districts have a changing population of students, including more English language learners, at the same time as they are working within a national context of higher standards (*Educating Teachers*, 2001). Teachers must address the needs of all students, particularly economically disadvantaged and minority students (Peck et al., 2007).

Diversity of teachers is important, too. Many of the teachers working with the ELL students (Lee et al., 2004) were native speakers of languages other than English and/or ESOL-certified. In a different way, diversity added depth to an online professional development course for pre-service teachers. Barnett et al. (2002) report that including practicing teachers in a discussion forum for pre-service teachers deepened the discussions about inquiry and teaching practice and also increased the pre-service teachers' motivation to be involved in the course. Having multiple practicing teachers in the discussions led to multiple perspectives which could not have been generated by pre-service teachers discussing the topics in isolation.

The ITEST program, with its continuing goal to involve students from backgrounds historically underrepresented in STEM, has wide ranging experience engaging students and teachers in inquiry learning. Effective inquiry for students from diverse backgrounds is clearly a research area to which ITEST projects can contribute useful and important findings.

Another opportunity arises in a description of the professional development offerings of four different science centers. Astor-Jack (2006) asserts that there is a gap in research around professional development provided for teachers by informal science centers, and that existing articles frequently focus solely on the centers' roles in introducing teachers to the centers' resources. As the ITEST community demonstrates, science centers and other organizations are bringing sophisticated professional development to teachers. Findings from the NSF ITEST program can inform this under-reported area.

Research methods for measuring teacher change

Measuring teacher change is a complex process that cannot be achieved with a simple research design. Researchers face significant challenges in trying to measure changes in practice, changes in beliefs, and the relationship between the two. In the following section, we describe the different methods most commonly used to measure teacher change and the challenges to measurement that have been raised by different researchers. Each study of teacher change needs to use the methods and instruments that are most relevant to the particular research question being addressed.

The table lists the principal instruments/methods that have been described in the studies in this literature review. The second column details the method as appropriate, and the final column provides the citation. It is important to note that the outcomes being measured differ depending on the research question, and so those studies which want to measure student outcomes as a result of teacher change will look to student assessment results, while those studies which seek to measure teacher attitude shifts will focus more on self-assessments by teachers.

	Notes	**References**
Teachers		
Questionnaires	General	(Ertmer et al., 1999; Lehman, George, Buchanan, & Rush, 2006; Park, Ertmer, & Cramer, 2004; Tal et al., 2001)
	Open-ended	(Jarvis & Pell, 2004; Tal et al., 2001)
	Technology beliefs	(Brinkerhoff, 2006)
	Technology competency	(Brinkerhoff, 2006)
	Computer self-efficacy	(Brinkerhoff, 2006)
	Technology integration	(Wang, Ertmer, & Newby, 2004)
	Science content	(Jarvis & Pell, 2004)
	Pre/post surveys (before and after PD)	(Harlen, Doubler, & n, 2004)
	Teacher self-assessed readiness to use inquiry methods	(Basista et al., 2001)
Online questionnaires		(Zerger, Bishop, Escobar, & Hunter, 2002)
Teacher interviews	Pre-post interviews	(Ertmer et al., 1999; Harlen et al., 2004; Kirk & MacDonald, 2001; Lehman et al., 2006; Luft, 2001; Park et al., 2004; Shuldman, 2004)
Interviews of Professional Development providers		(Astor-Jack et al., 2006; Lehman et al., 2006)
Artifact collection	District technology plan Online materials from district and state website	(Luft, 2001; Shuldman, 2004)
	Student assignments Teacher journals, portfolios, lesson plans	(Basista et al., 2001; Harlen et al., 2004; Lehman et al., 2006; Park et al., 2004)

Classroom observations	General Counts of question types	(Ertmer et al., 1999; Lehman et al., 2006; Luft, 2001; Park et al., 2004; Shuldman, 2004; Tal et al., 2001; Yip, 2004) (Yip, 2004)
Professional development observations	In-class responses, video, online postings	(Harlen et al., 2004)
Case studies		(Shuldman, 2004)
Ethnographic methods including extended observations, open-ended interviews		(Keys, 2005)
Students		
Student questionnaires		(Gerber et al., 2003; Jarvis & Pell, 2004)
Student interviews		(Gerber et al., 2003; Simonneaux, 2000)
Pre and post-test content assessments		(Basista et al., 2001; Gerber et al., 2003; Jarvis & Pell, 2004)
Student graduation test scores (or other standardized scores)		(Beglau, 2005; Gerber et al., 2003)

The questionnaires ask teachers to describe changes they have experienced in their teaching methods, their technology self-efficacy and knowledge, and their implementation of inquiry methods. All of these are teachers reflecting on their own learning and teaching, and in general, are most useful for measuring changes in teacher beliefs rather than practice. In some cases teachers are asked to take pre and post tests of knowledge, whether technology or content knowledge. These methods face a big challenge – that of social desirability. When depending on self-reports of attitude changes, teachers may well provide answers that they feel are more acceptable to the researchers. When using self-reporting of changes in practice, the threats to reliability are even greater, as teachers are not always effective evaluators of their own practice. Interviews can serve to triangulate the questionnaires, as the direct contact between interviewer and teacher can allow the teacher to explain responses in greater detail. However, social desirability responses can be even more pronounced in interviews.

When changes in practice are the focus, classroom observations are an important method to triangulate with teacher questionnaires and/or interviews. Observations allow researchers to document actual practices, and are often accompanied by an observation protocol, to help the research conduct uniform observations from class to class. Classroom observations tend to be limited in number, so researchers are not able to see teachers over a long period of time. Classroom observations are more time and money-intensive, which can limit their feasibility.

Another source of data includes collecting materials and/or artifacts. In many cases these are publicly available documents, such as online school demographic and achievement data, though in other cases they are classroom-based documents, including teacher class plans or journals. Finally, there are ethnographic methods for data collection, which take the methods described above, and conduct them more intensively and for a longer time period, usually in order to do an in-depth study of teacher change. Ethnographic methods can be the most effective way to observe and describe changes over time, but they are also the most time and money-intensive.

Students are generally used as sources of data for understanding teacher change in two formats: the most common is for those studies which use student achievement as an outcome, and seek to trace the relationship between a professional development program and student improved achievement. A second way that students are used for data collection is to obtain their views of the teaching and the classroom, whether through questionnaires or interviews.

Researchers trying to document changes in teacher practices and/or beliefs face great challenges. Each of the data collection methods described above has limitations, and even when a study is well-funded and has enough time, it is very difficult to measure the complex processes that entail teacher change. If student achievement is the desired outcome, this brings yet another obstacle, of the difficulty of assigning causality to any one program or teacher. Researchers continue to struggle with the most effective ways to measure change. In the next section, we outline some of the challenges that must be addressed.

Challenges to measuring teacher change

Changes in behavior and beliefs are long processes which almost invariably take more time than the life of any particular professional development cycle. In addition, the time period allowed for the treatment itself is often shorter than desired (Brinkerhoff, 2006; Ertmer et al., 1999; Tal et al., 2001; Wang et al., 2004). Thus, research that does not find a direct relationship between a particular program and teacher change may simply not be allowing enough time for the change to take place.

Even when researchers have more time, as with longitudinal studies, professional development programs are not administered in a vacuum. Participating teachers work within a complex context that has an impact on their actions and they participate in other professional development activities or change as a result of other factors (Brinkerhoff, 2006).

In the design of research studies on teacher change, identification of the outcome to be measured is crucial, and selection of data sources must be aligned to that outcome. Studies must develop an alignment between the professional development program, the outcome, and the method of measuring the outcome.

What teachers say they believe and/or practice is often different than what they actually believe and/or practice (Keys, 2005). Whether looking at outcomes of changes in teacher beliefs, or outcomes of changes in teacher practice, self-reported data (questionnaires and interviews) will have bias and some degree of social desirability (Brinkerhoff, 2006). It is very difficult to gather data on teachers' underlying values and classroom practices (Ertmer et al., 1999). Self-efficacy is difficult to verify with actual classroom use (Wang et al., 2004). And yet these outcomes, of underlying values and self-efficacy, are often outcomes that researchers want to look at.

Measuring the implementation of inquiry-based learning presents many challenges, not the least of which is arriving at a common, and measurable, definition of inquiry learning (Astor-Jack et al., 2006). Successful inquiry can look very different from one classroom to another, and researchers face the challenge of designing an observation protocol that will encompass the differences (Songer et al., 2003).

Attention to reaching underrepresented students is invariably held as an important goal but rarely followed by articulated strategies for doing so (Astor-Jack et al., 2006). This is one challenge that can be directly addressed by the work being done in ITEST projects around the country. The final section suggests a few areas of research opportunities for ITEST projects.

Conclusion: Research opportunities for ITEST projects

This literature review has provided background on the study of teacher change of beliefs and practice in science and technology. We have identified a number of areas where more research is needed, among them: longitudinal studies to trace change over time; research on the implementation of ‘second generation’ technologies at the middle and high school level; and research on the impact of teacher change on underserved students. ITEST projects are in a unique position to address each of these research areas.

Longitudinal studies to trace change over time: Each ITEST project is three years, allowing the opportunity to collect at least three years of data. In addition, because the ITEST program continues beyond the three years of each individual project, there is an opportunity for the community of practitioners to continue their research beyond the life of any particular ITEST project.

Implementation of second generation technologies at the middle and high school level: This is what ITEST comprehensive projects do. Simply documenting the myriad ways that the projects are bringing sophisticated technologies into the classroom through changes in teacher beliefs and practices would be a contribution to the field. ITEST projects provide teachers the opportunity to promote knowledge construction at the middle and high school level (Irving, 2006).

The impact of teacher change on underrepresented students: ITEST projects are unique in the population of students that they serve. Most studies of sophisticated technologies focus on higher education, or on suburban schools. ITEST projects serve underrepresented students, and provide a unique opportunity to look at the impact of access to sophisticated technologies, as well as the cultural aspects of changes in teacher beliefs and practices.

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