**Question 4: In your pre-prelim document you expressed an interest in examining the effectiveness of professional development efforts. How is effectiveness defined in the literature and what information is needed to determine effectiveness? Based on your readings for Questions 1-3, what other variables or measures (dependent and independent) have been used in studies of professional development for teachers and, more specifically, teachers of science? Have these same variables been used in studies of online professional development? Do any of these variables reflect the influence of pedagogical knowledge or pedagogical content knowledge on student learning or teacher instruction? Given what you now know, is effectiveness the most useful measure to employ in studies of online professional development in science education?**

Effectiveness as defined by the literature for professional development (PD) is agreed by many to come down to one primary overarching central driver, that of improving student learning (Banilower, Heck, & Weiss, 2007; Elmore, 2004; Feiman-Nemser, 2001; Garet, Porter, Desimone, Birman, & Yoon, 2001; Guskey, 2003; Hawley & Valli, 1999; WestEd, 2000; Yoon, Duncan, Lee, & Shapley, 2008). Some define student learning primarily as achievement scores measured by state and national standardized tests (Yoon, et al., 2008), while others define student learning more broadly and include improvement in student skills, attitudes, and knowledge (Banilower, et al., 2007). Figure 1 and Figure 2 provide a comparison of two different, but similar logic models that make the link between teacher professional development and student learning. Notice in both logic models that a combination of high quality instructional materials, curriculum, and assessment work in conjunction with professional development to improve classroom teaching and instruction, which ultimately increases student learning. Figure 1 elaborates on the supportive context necessary for effective professional development. It includes the following: (a) time for teachers to plan and collaborate, (b) administrator and community support, (c) sustainability components of resources, capacity, and structures (Banilower, et al., 2007). Figure 2 omits these components but shows the importance of student achievement as a feedback loop in driving future PD, teacher learning and instruction (Garet, et al., 2001). Some espouse looking at multiple student data throughout the year to assess the effectiveness of PD, such as: (a) student journals and portfolios; (b) individual student annual progress plans; (c) observation of student classroom discourse, projects, and presentations; and (d) test and quiz scores (Blumenfeld, Fishman, Krajcik, Marx, & Soloway, 2000; Fishman, Marx, Best, & Tal, 2003; WestEd, 2000). Others support and research the value of teacher learning portfolios as a tool to guide individual inquiry, learning, and reflection, which may lead to school-wide professional learning communities as portfolios are shared with colleagues (Milman & Kilbane, 2005; Sherman & Byers, in press; Simon & Johnson, 2008; WestEd, 2000; Xu, 2003).

While the overarching goal of professional development to improve the learning of teachers and in turn their students is not debated, making causal linkages between the effectiveness of specific PD initiatives and student achievement is very challenging given: (a) the complexity and inter-connectedness of the school system (Hewson, 2007), (b) the sociocultural climate, teacher apprehension, and tendency to resist change in school or district-wide reform efforts (Blumenfeld, et al., 2000; Darby, 2008; Elmore, 2004; Fullan & Miles, 1992; Weinburgh, Smith, & Clark, 2008), and (c) inherent difficulties in attributing the effects of PD to student achievement given the rapid change in technology-based solutions and difficulties in executing experimental studies in K-12 classrooms (Blumenfeld, et al., 2000; Dede, Ketelhut, Whitehouse, Briet, & McCloskey, 2009; Penuel, Fishman, Yamaguchi, & Gallagher, 2007). Experimental design research relating effective PD to student achievement as measured by state and national standardized test are thin (Banilower, et al., 2007; Garet, et al., 2001; Yoon, et al., 2008). Researchers are calling for studies that move beyond small qualitative case studies (Wilson, Floden, & Ferrini-Mundy, 2002), or large distilled, and sometimes uninformative, meta analysis (Guskey, 2003), to instead employ mixed method approaches for larger PD deployments across multiple districts and providers to determine the effectiveness of various models when looking to replicate efforts on a national scale (Borko, 2004). Still others look to combine development, research, and evaluation calling for design-based research methodology when technology-enabled online PD models are being evaluated (Dede, et al., 2009). So it would seem that while the methods to evaluate the effectiveness of professional development may vary, the overarching purpose to improve teacher and student learning is a common thread among most researchers, with broad agreement on the components of reform-based professional development (Banilower, et al., 2007; Hawley & Valli, 1999; Hewson, 2007; Horizon Research, 2006; Loucks-Horsley, 1999; National Staff Development Council, 2008; WestEd, 2000). The following PD categories and models are cited across the literature:

1. Traditional PD typically provides training from one to many with the purpose of demonstrating or disseminating theories, strategies, and

techniques through workshops, conferences, institutes, or college courses, and are usually delivered by some internal or external expert (Guskey, 2003; National Staff Development Council, 2008; U.S. Department of Education, Institute of Education Sciences, & National Center for Education Evaluation and Regional Assistance, 2008). If these traditional PD experiences are not linked as part of an on-going school-based effort with follow-up, these isolated or fragmented PD models are highly suspect as to their effectiveness (Albert Shanker Institute, 2002; Elmore, 2004; Garet, et al., 2001; National Staff Development Council, 2008).

2. Reform or integrated PD, is typically part of a school-wide reform or improvement plan, and includes teachers reflecting on their own practice in light of student data and may include the following strategies: (a) study groups, (b) coaching or mentoring, (c) peer-observation and assessment, (d) curriculum integration, (e) inquiry-action research, or (f) individually guided activities (Garet, et al., 2001; Guskey, 2003; Hewson, 2007; National Staff Development Council, 2008; Penuel, et al., 2007; U.S. Department of Education, et al., 2008). If these efforts are perceived as top-down, punitive, or do not involve collaborative management, teamwork, and stakeholder input from teachers that acknowledges their career experience and expertise, the reform efforts may inculcate teacher apprehension, fear, anger, and lowered self-confidence levels, leaving teachers disenfranchised and disengaged from the reform effort (Darby, 2008).

3. Immersive PD opportunities are typically long duration experiences and provide teachers of science with in-depth learning opportunities in science as they work with scientists helping them conduct authentic research on-location through internships, fellowships, or summer field work ("America Competes Act ", 2007; Locks-Horsley, Stiles, & Hewson, 1996; National Research Council, 1996; U.S. Department of Education, et al., 2008).

From the large scale reviews of experimental, quasi-experimental, and teacher self-report studies, it appears effective professional development needs to be of sufficient intensity and duration to affect change in teacher practice regarding integration of reform-based curriculum. Researchers suggest at least 49 to 80 hours of PD over the course of a school year, and not administered as a single “one-shot” experience, but linked to authentic classroom instruction (Banilower, et al., 2007; Garet, et al., 2001; Supovitz & Turner, 2000; Yoon, et al., 2008). One of the biggest challenges for effective professional development is that of providing sufficient time for teachers to reflect, discuss, create, analyze, and plan both individually, and with colleagues to craft improvements in instruction based on student work and student assessment data (Fullan, 2007; Fullan & Miles, 1992; National Staff Development Council, 2008; Penuel, et al., 2007; Penuel & Means, 2004; WestEd, 2000). When one juxtaposes the total hours of PD completed against the large scale survey data discussing the amount of time teachers receive for PD over the course of a school year, one begins to see the challenge in administering effective PD solutions. A review of the 2003-2004 federal Schools and Staffing survey, conducted by the National Center for Education Statistics found that 57% of all teachers received less then 16 hours of professional development during their prior school year, and only 23% received more then 33 hours of PD over the same period (National Staff Development Council, 2008). Research suggests a threshold of at least 30 hours of PD to effect change in teachers' classroom practices (US Department of Education, Institute of Education Sciences, National Center for Education Evaluation and Regional Assistance, & Regional Educational Laboratory Southwest, 2007), with significant results occurring after 49-80 hours (Banilower, et al., 2007; Supovitz & Turner, 2000; Yoon, et al., 2008). Given this deficit, one can see we are already failing to empower our teachers with adequate opportunities to make substantive changes in their classroom practice.

In addition to the dependent variables of frequency and duration as measures of effectiveness, other research suggests PD that targets increasing teachers' science content knowledge and pedagogical content knowledge as worthwhile variables to improve student learning, rather then PD that focuses on generic pedagogy or teacher classroom behavior strategies (Garet, et al., 2001; Heywood, 2007; Kennedy, 1998; Parker, 2004; Penuel, et al., 2007; U.S. Department of Education, 2000). The linkage between teachers' knowledge of science content and pedagogical content knowledge as subject matter for effective professional development in science education at the K-8 grade levels is strongly supported in the literature regarding conceptual change, science education, and how students learn (Appleton, 2007; Bransford, Brown, Cocking, Donovan, & Pellegrino, 2000; Driver, Asoko, Leach, Mortimer, & Scott, 1994; Driver, Guesne, & Tiberghien, 2000a, 2000b; Feiman-Nemser, 2001; Heywood, 2007; Monk, 1994; Posner, Strike, Hewson, & Gertzog, 1982; RMC Research Corporation & Center on Instruction, 2008). Teachers' abilities to effectively plan and facilitate students' construction of knowledge in making sense of the world around them is intimately tied to: (a) teachers' deep understanding of the science content, (b) awareness of common challenges students may encounter in dealing with science phenomenon, and (c) knowledge of strategies, representations, and models that might be used to bridge between the gap between students existing knowledge and that under instruction (Bransford, et al., 2000; Brown, 1992; Brown & Clement, 1989; Feiman-Nemser, 2001; Luera, 2005). This said, sensitivity should apply regarding the complexity of science content knowledge for elementary teachers who are generalists and responsible for teaching a wide range of subjects (Heywood, 2007; Luera, 2005; Parker, 2004). For a detailed review of this area, please see prelim question three regarding pedagogical content knowledge. In spite of the insufficient hours of overall PD provided for teachers, the emphasis on content knowledge and how to teach it appears to be focused correctly, with 83.4% of teachers reporting their PD targeted how to teach specific content over the 2003-2004 school year, which is also corroborated with 23% of all teachers requesting content-related PD as the number one priority for their professional development (National Staff Development Council, 2008). These results are buttressed by a large sample survey discussed in prelim exam question one, finding elementary teachers lack confidence in both science subject matter as well as how to teach via inquiry-based methods (Horizon Research, 2001, 2002). Thus, professional development for elementary science teachers that facilitates a deeper understanding of science content within a conceptual framework using inquiry-centric pedagogy would seem worthwhile and research supports this as an effective means to learn the science content for prospective elementary teachers (Hanuscin & Lee, 2008).

Given this data, one observation regarding professional development might not be focused on teachers' inabilities to successfully implement inquiry-based lessons, but administrators' challenge to appropriate adequate funding, time and the structure necessary to enact improvements called for in the literature regarding "effective" school-based PD reform models (Elmore, 2004; National Staff Development Council, 2008; U.S. Department of Education, et al., 2008; WestEd, 2000). To briefly elaborate, features of "reform-based" professional development seem to be converging on school-based models that have the following components: (a) clear, agreed upon student learning goals and a common school vision to focus and shape teacher learning; (b) an expanded array of aligned PD opportunities that include formal, informal, and internal and external expertise and partnerships; (c) teacher learning that is on-going, job embedded and involves iterative improvement through group review of student work and data; (d) shared governance and collaborative team decision making for larger school-wide issues; (e) structured time for teachers to collaboratively meet both within grade and across grades as student progress is regularly monitored and actions are adjusted in light of data; and (f) distillation and enactment of broader school-wide improvement plans through individual teacher-developed action plans and portfolios (Darby, 2008; Elmore, 2004; Fishman, et al., 2003; Hawley & Valli, 1999; Locks-Horsley, et al., 1996; Milman & Kilbane, 2005; Sherman & Byers, in press; Simon & Johnson, 2008; WestEd, 2000; Xu, 2003). In essence, researchers are supporting the importance of professional learning communities or collective school participation that is centered on increasing student learning as part of an on-going culture of continuous improvement (Darby, 2008; Elmore, 2004; Fishman, et al., 2003; National Staff Development Council, 2008; Penuel, et al., 2007). When PD is not part of a school-wide culture of improvement, teachers involved in PD initiatives may encounter significant backlash from other teachers not part of the PD, undermining the impact of the entire effort (Owston, Sinclair, & Wideman, 2006; Weinburgh, et al., 2008). Within these broad strokes of effective school-based PD reform, implementation strategies may incorporate some combination of the following: (a) mentoring or coaching which may involve both internal or external expertise, (c) study groups or collective school-wide participation, (d) peer observations and collaboration, (e) action-research inquiries, (f) individual PD activities as part of a long term growth plan, and (g) curriculum implementation efforts (Darby, 2008; Darling-Hammond & McLaughlin, 1995; Fishman, et al., 2003; Garet, et al., 2001; Guskey, 2000; Hawley & Valli, 1999; National Staff Development Council, 2008; Penuel, et al., 2007; Penuel & Means, 2004). Thus, when evaluating or designing "effective" professional development, possibly looking at the existence and combination of the following components is prudent: (a) consider how the PD may be catered to the local needs and contexts in which it is deployed, (b) determine the degree of fidelity to which the program is implemented, (c) consider the technical support resources necessary for implementation, and (d) consider how the PD program components are enacted with respect to supporting teachers' actual classroom practice (Linn, 2006; Penuel, et al., 2007; Penuel & Means, 2004; Varma, Husic, & Linn, 2008). Elmore (2004) posits that school-wide student learning as a result of school-based professional development is not a linear progression, but one that iteratively rises and plateaus as the effects of certain initiatives are achieved. He and others recommend the assistance of external partners, such as universities, may be valuable in observing classroom practices of individual teachers and facilitating “next step” discussions as schools strive to make continued improvements as plateaus are reached (Darby, 2008; Elmore, 2004; Fishman, et al., 2003; National Staff Development Council, 2008; Penuel, et al., 2007). Given the level of accountability mandated to teachers and schools by the federal government, Elmore (2004) argues that “the law of reciprocity” (p. 251) warrants administrators are equally charged to empower teachers with the opportunity to be successful in what they are asked to achieve in the classroom. For teachers are the agents of change in student learning, operating at nexus of curriculum, instruction and assessment (Cuban, 1990; Elmore, 2004). From the discussion above, and looking at the data regarding the duration, intensity, and type of PD currently provided to elementary science teachers, education administrators at all levels (e.g., school, district, state and federal), play a crucial role in providing the resources, capacity, and structures necessary to sustain effective PD as depicted in Figure 1.

Another critical area that is of primary concern in effective PD, including those at the elementary level, deals with addressing teachers’ beliefs and orientations toward science education, their perceptions regarding their confidence in how to teach science, and their epistemological and ontological beliefs regarding the nature of science and understanding of science concepts, respectively (Howitt, 2007; Kang, 2007; Pajares, 1992). As addressed in prelim question three regarding pedagogical content knowledge, a large body of research shows that beliefs, attitudes, perceptions, and personal experiences affect part of a larger belief system that is deeply seated, resistant to change, and inconsistent. Ultimately, this belief system affects the pedagogical strategies elementary teachers employ, the content areas they emphasize and desire to learn , and the instructional time they allocate to different subjects in their classrooms (Brickhouse, 1990; Horizon Research, 2003; Jones & Carter, 2007; Kang, 2007; C. A. Lee & Houseal, 2003; Morine-Dershimer & Kent, 1999; Munck, 2007; Nespore, 1987; Pajares, 1992; Parker, 2004; Posner, et al., 1982; Schmidt & Buchman, 1983; Simmons, et al., 1999; Tobin & Fraser, 1990; Wenner, 1993; Yerrick, Parke, & Nugent, 1997). Literature at the elementary level documents the generality that many elementary teachers tend to have a lack of confidence in their understanding and ability to effectively teach science content, as well as a fear or even dislike for the discipline (Appleton, 2002, 2007; Czerniak & Lumpe, 1996; W. Harlen, 1997; Howitt, 2007; Jones & Carter, 2007; O. Lee, 1995; Shallcross, Spink, Stephenson, & Warwick, 2002). Transfer of professional development into classroom practice may be enhanced if one is able to increase teachers' self-efficacy in inquiry-based instruction and content knowledge, if teachers believe it will positively affect student learning (Bandura, 1977; Duran & Duran, 2005; Plourde, 2002). Similarly, the independent PD variable of coherence, has been shown to be a significant predictor of teachers' implementation of PD curriculum (Garet, et al., 2001; Penuel, et al., 2007). Coherence is typically defined as teachers' perceived alignment of PD to: (a) local curriculum and other PD experiences, (b) teachers' personal PD needs, and (c) student learning goals (Garet, et al., 2001; Penuel, et al., 2007). Given this knowledge, professional development that hopes to be effective attempts to address teachers' beliefs, self-efficacy, and prior experiences by: (a) acknowledging these and requesting teachers monitor their beliefs reflectively through journals and portfolios; (b) facilitating teacher discourse to share their views with colleagues in a safe environment; (c) developing teacher confidence through modeling effective strategies with hands-on practice in situ;

(d) video-tapping ones' lessons, then reviewing and discussing them with colleagues; and (e) providing on-site follow-up via coaching models that may include in-school peer collaboration and classroom observations (Akerson, et al., 2009; Asbell-Clarke & Rowe, 2007; Fishman, et al., 2003; Glasson & Lalik, 1993; W Harlen & Doubler, 2004; Howitt, 2007; Krall, Straley, Shafer, & Osborn, 2009; Varma, et al., 2008; WestEd, 2000). It should be noted that teacher attitudes, which in part represent an outward expression of ones' beliefs (Munck, 2007), when measured via simple attitudinal surveys are not always representative of more deeply held tacit beliefs (Yerrick, et al., 1997). Similarly, attitudes are not necessarily predictors or representative of later classroom practice in elementary science instruction (Munck, 2007; Simmons, et al., 1999; Yerrick, et al., 1997).

Some find that isolated summer PD institutes with intermittent follow-up are not in and of themselves sufficient to affect long-term changes in teachers' beliefs and pedagogical practices (Akerson, et al., 2009; Yerrick, et al., 1997). Supporting this claim Guskey (1986) offers a unique perspective stating that teacher beliefs and attitudes do not change as a result of being "pitched" the value of a particular method or approach, but change after a teacher has implemented an approach in his or her classroom and observed its effectiveness with students. Only then is the teacher "sold" on the approach and will incorporate a positive impression of the method into his or her belief system. The old adage, seeing is believing seems to apply, where first hand experience confirming the success of a particular strategy, program, or technique serves as a prerequisite before a teacher's commitment to the strategy will become part of his or her regular classroom practice (Briscoe & Peters, 1997; Guskey, 1986). Posited over 20 years ago, this approach is essentially what occurs with on-going school embedded PD that analyzes student work and data, iteratively improving and refining pedagogical methods over time to increase student learning. There is emerging research utilizing these reform-based models and school-based strategies which show promising and positive results (Darby, 2008; Fishman, et al., 2003; WestEd, 2000). With the broad strokes of variables considered for effective PD discussed that include the importance of addressing: (a) science content and pedagogical content knowledge, (b) teacher beliefs, (c) duration and frequency of PD, and (d) various strategies of reform-based PD, a more detailed look at several studies will enumerate the dependent and independent measures examined within professional development.

## Dependent Measures in Professional Development

As shown in the selection of various PD studies in Table 1, dependent measures in science education PD research typically examine treatment for changes in: (a) teacher attitudes, beliefs, perceptions, and self-efficacy concerning science content or inquiry-based pedagogical skills (b) teacher content knowledge, (c) teacher pedagogical content knowledge or inquiry-based pedagogical skills (d) classroom practice and application of content learned through PD, and (e) student learning or attitudes in science as a result of the professional development. As discussed before, measuring effects of PD on student learning, while considered by many as the “holy grail” for professional development, present a myriad of challenges given: (a) direct measurement is difficult given the complexity of schools and socialcultural dynamics at play (Hewson, 2007), (b) the costs necessary to obtain data on a large scale as many teachers are needed to detect small effects (Penuel, et al., 2007), (c) difficulty in employing rigorous experimental designs without proper planning and district cooperation (A.J. Wayne, Yoon, Zhu, Cronen, & Garet, 2008) , and (d) the necessity to corroborate results longitudinally across a variety of PD programs and providers (Borko, 2004). Several of the studies listed in Table 1 are discussed above (WestEd, 2000), or are discussed in detail in prelim questions one and two regarding online professional development and what is possible in online learning (e.g., remote labs, blended PD, etc.) and as such, will not be discussed in detail here (Asbell-Clarke & Rowe, 2007; Berger, Eylon, & Bagno, 2008; del Valle & Duffy, 2009; W. Harlen, 2004; Krall, et al., 2009; Owston, et al., 2006; Varma, et al., 2008). In addition to the dependent variables that look at teacher and student impact as a result of PD, Table 1 also shows there are a wide variety of delivery models utilized in PD across all grade levels.

## Independent Measures in Professional Development

Independent measures in science education professional development vary, but in general at the programmatic level they may include: (a) barriers to implementation of PD (e.g., release time, administrator support, school culture, access to and type of technology employed); (b) technology support provided; (c) type of PD activities employed (e.g., traditional versus reform-based, hands-on active engagement versus passive lecture-based learning); (d) time span and duration of PD; (e) coherence of PD (e.g., perceived PD alignment to curriculum, teacher, and student needs); (f) cost to deliver PD; and (g) feedback on the PD model itself, evaluating design parameters such as location, structure, delivery mode, media, support provided, and selected content (Akerson, et al., 2009; Asbell-Clarke & Rowe, 2007; Berger, et al., 2008; Fishman, et al., 2003; Garet, et al., 2001; W. Harlen, 2004; Krall, et al., 2009; Linn, 2006; Overbaugh & Lu, 2008; Penuel, et al., 2007; Penuel & Means, 2004; Varma, et al., 2008; A.J. Wayne, et al., 2008; WestEd, 2000). With respect to the independent variables regarding teacher characteristics, researchers have looked at many variables, which include: (a) years teaching experience; (b) certification or licensure within teaching area, or national board certification; (c) major, minor, or graduate degree in teaching area; (d) number of college courses taken in the field one is teaching; (e) major or minor in science as compared to general education degree; (f) gender; (g) grade levels taught (e.g., elementary, middle high school); (h) teacher SAT and GPA scores; and (i) quality of college or institution attended. While some of these variables are included in larger PD studies, like gender or certification held, and usually find no significant effects, many of these variables are part of a series of studies which examine the factors that attempt to measure what constitutes a "highly qualified" or "effective" teacher. Primarily generated from the education production literature these studies use the proxy measures above to see if there is a relationship between independent teacher characteristic variables and student achievement as measured by state and national standardized tests (Druva & Anderson, 1983; Economic Policy Institute, 2003; D. Goldhaber & Anthony, 2007; D. D. Goldhaber & Dominic, 2000; Monk, 1994; National Bureau of Economic Research, 2007, 2008; Rivkin, Hanushek, & Kain, 2005; US Department of Education, et al., 2007; Andrew J. Wayne & Youngs, 2003; Whitehurst, 2002). Not related to PD research, these studies generally find it difficult to disaggregate proxy measures and show large significant effect sizes for any single teacher characteristic on student achievement, but collectively, the measures demonstrate a positive correlation with student achievement at the secondary level in the following areas: (a) undergraduate degree and major in science, (b) number of undergraduate college courses in science, and (c) years experience within the first three years of teaching (Economic Policy Institute, 2003; Whitehurst, 2002).

After a review of selected experimental and quasi-experimental studies, Whitehurst (2002) concludes that individual teacher characteristics pale in comparison to the main effects of school-wide reform-based PD on student achievement, which is also corroborated by case study research (Darby, 2008; WestEd, 2000). Still other researchers preempted Borko's (2004) and Wayne, Yoon, Zhu, Cronen, and Garet's (2008) recommendations to look across large scale PD programs for common features shown to be effective (Garet, et al., 2001; Supovitz & Turner, 2000), and even though Borko (2004) and Wayne et al. (2008) differ in their preferred methodology, research is beginning to emerge in response to this call (Banilower, et al., 2007; Buzhardt, Greenwood, Abbott, & Tapia, 2006; Penuel, et al., 2007; Penuel & Means, 2004; Varma, et al., 2008; Yoon, et al., 2008).

Collectively, these studies tend to focus on dependent variables concerning the fidelity of the PD program being implemented (e.g., features, duration, time span, providers, costs, and rate of implementation), and changes in teacher knowledge, self-confidence and classroom practice. When looking at the variables analyzed in online PD, as discussed in prelim question one, Dede et al. (2006; 2009) calls for examining a program's impact on student learning within the context of research that: (a) creates a transformative and lasting change in teachers, (b) is scalable and sustainable, and (c) employs an iterative design-based approach incorporating formative assessment as well as summative impact. While these outcomes are similar in nature for face-to-face PD goals, Dede (2009) and others recommend different measures to gauge learning impact, given what is afforded in online environments such as: (a) web logs, (b) critical discourse analysis (Lowes, Peiyi, & Yan, 2007), (c) “click-through” footprints (del Valle & Duffy, 2009), (d) content creation capability (McLoughlin & Lee, 2008), and (e) goal level attainment within immersive games (The Education Arcade & Massachusetts Institute of Technology, 2009). Online professional development adds a layer of technology-enabled complexity and transactional distance (Moore, 1993), discussed in prelim questions one and two. These additional layers of complexity, while affording access to content, tools, and expertise that might not be available otherwise, bring with them potential barriers and additional overhead with respect to capacity and resources, such as: (a) technology access, (b) on-site and off-site technical support, (c) Internet connectivity, and (d) teacher technical acumen necessary to imbibe in the program (Blumenfeld, et al., 2000; Linn, 2006; Overbaugh & Lu, 2008). This supports why Dede (2009) suggests a design-based research approach that explores the effectiveness of PD program design, seeking not only to confirm what or if learning is occurring, but also, why and how it transpires, and how it may be iteratively improved. As reflected in Table 1, dependent measures for PD appear stable across all forms of PD, online or otherwise, regardless of grade level, but the mechanisms for delivery and measures for evaluation vary considerably, depending on the context and purpose for the professional development. This variance in models is corroborated by Fishman, Marx, Best, and Tal (2003) and others (Blumenfeld, et al., 2000), who argue that no model of PD should be advocated as the single “best” approach. While several studies in Table 1 have already been discussed, a brief look at two additional studies will highlight the variables and the impact of their PD approach related to science education at the upper elementary and middle school levels.

# Exemplars: Two Professional Development Studies

Sound instructional design principles recommend using exemplars and non-examples to facilitate learning; the same approach will be used herein to provide contrasting case examples. The first study will highlight the components of an effective PD design that is: (a) tied to the local school curriculum, (b) iterative over time, (c) delivered in partnership with external expertise and teacher input, and (d) driven by student data. This study ultimately increased the effectiveness of teacher practice and showed significant gains in student learning directly linked to the PD provided (Fishman, et al., 2003). The second non-example, while at first blush appears to have some of the components of effective professional development, demonstrated less then optimal results (Akerson, et al., 2009).

## *School-Based Design Driven by Student Data*

Fishman et al. (2003) provide a thorough research design that makes use of multiple data measures such as classroom observations, student assessment data, and teacher self-report data to track the effectiveness of their professional development evaluation study, making the causal link between PD and student learning. Fishman et al. (2003) state they are not advocating any particular PD model, but an approach to study the impact of PD with the goal of increasing its effectiveness and efficiency. Through a standards-based reform model focused on inquiry-oriented science education with embedded technology to facilitate learning, Fishman et al. (2003) demonstrate the linkage from teachers' learning through PD to improved student learning as the PD curriculum is actively applied and monitored in the classroom. Shown in Figure 3, their model for teacher learning incorporates teachers' knowledge, beliefs, and attitudes as affected through the enactment of PD design elements and the curriculum, which then, based on evidence of student performance, cycles back to affect changes in teachers' attitudes, as well as an improvement in teachers' content knowledge and pedagogical skills as student learning is increased (Fishman, et al., 2003). This approach incorporates the logic posited by Guskey (1986), and that is successfully demonstrated in other reform-based studies (Darby, 2008; Duran & Duran, 2005). The PD framework Fishman et al. (2003) apply seeks to blend the four elements of content, strategies, sites, and media to improve teacher and student learning. The Fishman et al. (2003) approach begins by answering the simple question typically posed by instructional designers (Dick, Carey, & Carey, 2008): What is it that we want the students to learn as a result of the professional development (Fishman, et al., 2003)? Through a model that begins by looking at student assessment data to guide the selection of PD needed, rich discourse with teachers diagnose reasons for student learning challenges, which then leads to planning and later implementation of targeted PD (Fishman, et al., 2003). In the case of this study, the targeted PD was administered over multiple six-hour face-to-face Saturday workshops. Fishman et al. (2003) observed classrooms and student performance as they continued to improve the PD necessary to increase teachers' abilities and knowledge, which then lead to a significant increase in student learning over time. Converse to measuring impact through distal and remote measures such as state and national standardized assessments respectively, Fishman et al. (2003) argue these measures are too far removed to observe the impact of local PD efforts, and instead suggest "close," "immediate," and "proximal" measures such as student classroom discourse, student journals, embedded assessments, and end of unit curriculum tests as more effective (p. 646). This PD approach demonstrated significant gains in student learning using student pre- and post-tests results over successive years of a unit on watersheds and water quality for middle school students. Fishman et al. (2003) argue because PD is contextually linked to the unique needs of students, teachers, and the environment in which it is targeted, no one model is more effective then another, but instead recommend PD providers focus on: (a) job-embedded PD that is designed with the input of teachers, and (b) iterative improvement driven by student learning outcomes over time. This design approach seems to be effective for the dependent measures of import to professional development. Contrast this approach with another PD study that sought to increase teachers' knowledge of inquiry, the nature of science (NOS), and scientific modeling, which was not explicitly linked to local curriculum or driven by improving student learning, and the results were less substantive (Akerson, et al., 2009).

*Summer Institutes with Follow-up Workshops and Classroom Support*

Akerson et al. (2009) delivered a K-6 PD model for 10 active elementary teachers as part of a university-school district partnership that involved a two-week summer institute with two follow-up workshops during the succeeding school year. This model also included on-site classroom support (i.e., modeling of inquiry lessons and materials support) that was administered through graduate students and an education outreach coordinator in the life sciences. Researchers documented a case study of four educators and confirmed research about elementary teachers' lack of mature knowledge concerning NOS and inquiry-based instruction (Appleton, 2007). While positive gains were reported in teachers' ability to design and conduct inquiry-based lessons, initial gains in understanding NOS and scientific modeling faded as the teachers returned to the classroom. The researchers posit the following recommendations to ameliorate this effect: (a) tighter coupling between summer and follow-up workshops focusing on how NOS and modeling play into inquiry-based lessons, (b) increase the frequency of follow-up workshops, and (c) decrease the cognitive load for the PD program goals that attempted to facilitate acquisition and application of inquiry, NOS and scientific modeling (Akerson, et al., 2009). Interestingly, a prior study by Akerson, Morrison, and McDuffie (2006), found a similar fade effect for prospective elementary teachers after an entire semester focused on learning about the nature of science. The Akerson et al. (2009) study highlights two important perspectives given the literature on elementary teacher professional development.

First, as previously discussed throughout these preliminary exam questions, teachers' classroom instruction is affected by their belief system and prior education experiences, which for many elementary teachers, does not include exposure to inquiry or constructivist-based pedagogy, such as the learning cycle (Glasson & Lalik, 1993; Hanuscin & Lee, 2008), thus highlighting a critical area for effective elementary teacher PD (Banilower, et al., 2007). Research from conceptual change and science education literature (Akerson, Flick, & Lederman, 2000; Appleton, 2002; Driver, et al., 2000a; Feiman-Nemser & Parker, 1990), how people learn research (Bransford, et al., 2000), and findings from national teacher surveys and classroom observation studies (Horizon Research, 2002, 2003, 2006), stress the necessity to couple science content knowledge within its pedagogical implications to facilitate inquiry-based lessons as a crucial area of importance in PD at the elementary and middle school grades (Duran & Duran, 2005; Luera, 2005). This makes sense within the K-8 grade levels given there are many teachers who have generalist K-8 teaching certificates that provide little background in their preservice training focused on science (Horizon Research, 2001; Luera, 2005). It may not be an “either/or” proposition, deciding if elementary science PD should highlight content knowledge or NOS and inquiry, but instead we might focus on facilitating learning both science content and inquiry-based strategies in a blended approach incorporating features such as: (a) individual teacher reflections and collaborative discourse (Bryan & Abell, 1999; Duran & Duran, 2005), and (b) knowledge of how students learn including strategies and representations of phenomenon to facilitate students’ understanding (Bransford, et al., 2000; Shulman, 1986, 1987). Hanuscin and Lee (2008) demonstrated combining science content knowledge and inquiry-based pedagogy as a model for teacher learning has yielded very positive results for prospective elementary science teachers, which helped them to identify their own science content misconceptions and didactic teaching styles. In essence, the model doesn’t have teachers learn physical science as separate and distinct from learning inquiry, but in learning how to teach physical science, teachers also learn the science content knowledge situated within the context of inquiry-based practice and discussion of how students’ learn.

Secondly, the Akerson et al. (2009) model did not appear to be part of a school-wide effort, or tied into local school-based study groups, which may partially responsible for it lack of sustained impact. The Akerson et al. (2009) research is very similar to another study that utilized a two-week summer institute at a university campus approach with follow-up site visits using the same FOSS hands-on inquiry kits (Duran & Duran, 2005). In the PD model by Duran et al. (2005), they phased in their delivery of school support and PD content over several years with more follow-up visits to an apparently greater impact as reported in their results for teacher self-efficacy and implementation via a school-based reform model. Although, the duration of PD contact and frequency of follow-up visits does not in and of itself guarantee success as Brisco and Peters (1997) provided a three week summer institute for elementary teachers with classroom visits twice a month for an entire semester, but found in-school peer-collaboration groups as a critical factor for success. Also, the work of Barab, Barnett, and Squire (2002) provide an insightful qualitative vignette of tensions that are at play with a community, which are a necessary part of its evolution as one attempts to maintain a thriving community over time.

For those that seek to provide follow-up PD support throughout the school year, as expressed in the Akerson et al. (2009) study, they may be well served to consider incorporating a higher degree of technology-enabled support tools that can assist in facilitating on-going collaboration via networked communities of practice (Barnett, 2002; Signer, 2008). Although, research shows even the best technological solutions and instructionally sound designs for online communities will not necessarily guarantee a high volume of teacher participation (S. Barab, The ILF Design Team, Makinster, Moore, & Cunningham, 2001; Schlager & Fusco, 2003). Those that build on the local contextual needs of the schools and teachers they are serving may achieve better results (Schlager & Fusco, 2003). Alternatively, there is also research confirming the value certain teachers find in emoting issues and problems in large national communities of practice, where anonymity readily permits them to seek advice or encouragement from others outside the local community (Hur & Brush, 2009). It would seem that a dynamic repertoire of online and face-to-face PD strategies and methods be available for enactment based on the local improvement goals of schools, as well as the individual needs and preferences of teachers (National Research Council, 2007).

## A Different View of Effective Professional Development

A different tact to take in determining attributes of effective PD may be to look at what constitutes effective science instruction and use this as a guide to determine if the PD being delivered is successfully assisting teachers to increase their practice in this direction. In a recent review of the research literature, Banilower, Cohen, Pasley, and Weiss (2008) generated a commissioned report looking specifically at defining effective science instruction. Building off the knowledge of conceptual change literature, how student learn, and the importance of inquiry-based instruction they recommend effective science instruction has the following components: (a) motivates students, (b) elicits students' prior knowledge, (c) engages students in intellectually relevant questions, (d) encourages students' use of evidence to critique claims, and (e) facilitates students making sense of their new knowledge (RMC Research Corporation & Center on Instruction, 2008). To motivate students the RMC report (2008) posits engaging students using a "hook," such as an authentic problem or question derived from the real world and students' interests, or possibly a discrepant event, to spur students' intrinsic desire to learn through their natural curiosity and cognitive dissonance (Driver, et al., 2000a, 2000b; Glasson & Lalik, 1993). Eliciting students' prior knowledge draws on the collective research of how students learn (Bransford, et al., 2000), which suggest that deeper, active, and long term conceptual understanding occurs when knowledge is built upon students' prior experiences, allowing them to formulate new ideas through addressing relevant intellectual questions. Through questioning, inquiry, and formative assessments, teachers' help make students' thinking visible and encourage use of evidence to support student conceptual understanding (RMC Research Corporation & Center on Instruction, 2008). In essence, it is the role of the teacher to structure a learning environment where students may engage in these types of learning experiences as situated within a specific science domain and its respective conceptual framework. To the degree that professional development (online or otherwise) is able to facilitate elementary teachers' ability to design, deliver and assess instruction in this way, it is marching toward what the research defines as effective instruction to improve student learning as espoused in the national science education reform standards (American Association for the Advancement of Science, 1993; National Research Council, 1996).

The question then concerning what information is needed to determine the effectiveness of professional development from a review of the research would appear to focus on the following:

1. The total duration or contact hours of PD should be of a sufficient magnitude (49-80 hours).
2. The frequency of PD contact should be over a specific duration, on-going over the course of a school year, avoiding "single-shot" exposures.
3. The degree to which PD incorporates active or reform-based strategies that include components such as: (a) school-based study groups, (b) coaching or mentoring, (c) curriculum integration, (d) inquiry action research, (e) individually guided activities, and (f) immersion field experiences with scientists. The strategies are not meant to be a check list to enact within a school, but through appropriate review of student

learning artifacts, assessment data, etc., be selected as part of a comprehensive school-wide improvement plan that is periodically reviewed, updated, and adjusted in light of student improvement through targeted PD enacted through the strategies above.

4. The degree to which PD is part of a cohesive set of experiences, that may include traditional PD opportunities (e.g., workshops, conferences, seminars, institutes), as long as they fit within a teachers' long term PD growth plan and have follow-up that transform the experience to one of active engagement, reflection and application in the classroom (Garet, et al., 2001; National Staff Development Council, 2008).
5. The degree to which the PD addresses teachers' existing belief system facilitating: (a) the importance of science literacy, (b) increased self-efficacy in teaching science (content and pedagogical knowledge), and (c) an informed perspective and understanding of the nature of science.
6. The degree to which the PD addresses specific science content knowledge, and the pedagogical implications of that knowledge to facilitate student learning (e.g., understanding of how students learn, ability to design and implement inquiry-based learning strategies, knowledge of common difficulties students may encounter in learning certain science concepts, command of a repertoire of analogies and representations to help illustrate certain science topics, and knowledge of formative and summative assessments and questioning strategies).

7. The degree to which the appropriate support structures are enacted that permit the professional development to stand a chance of making its desired impact on student learning (e.g., administrator and policy support, physical access to materials and technology, technical support for teacher use and classroom implementation, school structure to facilitate study groups or professional learning communities, and release time for within and across grade planning).
8. For online professional development, information to be collected might include: (a) type of PD model and strategies employed, blended or otherwise; (b) type of media used or combination thereof; (c) existence of teacher familiarization or acclimation to online PD components; (d) delivery mode(s) used; (e) online moderator expertise; and (f) teacher perception, participation, and utilization in various online components or tools. The program technical design should also be evaluated in light of a theoretical framework and established research questions to guide the improvement of online PD model development.
9. When looking across the PD landscape, a mixed method approach of large scale cases might capture information such as: (a) the overall size, dispersion, and number of deployments; (b) variations in implementation fidelity; (c) variations in PD providers' expertise; (d) variations in local context; and (e) variations in cost of delivery, all of which should seek to inform overall effectiveness and efficiency of PD programs across multiple state and district implementations.

10. Lastly, coupled with all this information, PD should move beyond simple documentation of “inputs” and incorporate Guskey’s (2003) five levels of evaluation: (a) teachers’ reactions, (b) teachers’ learning, (c) organizational support and change, (d) teachers’ transfer of knowledge and skills to the classroom, and (e) student learning outcomes.

The list of information available to determine the effectiveness of professional development is obviously extensive, and presents no small effort for those that seek to evaluate PD across the many facets of inputs, outputs, and outcomes available. Large scale mixed method longitudinal studies that “drill deep” using a reform-based PD perspective appear to be where the consensus is heading for what constitutes effective PD and how it should be evaluated. Unfortunately, challenges in coordinating cohesive research across the areas of online PD litter the current landscape (Dede, 2006; Dede, et al., 2009), and funding for evaluation in areas like teacher preparation appear in short supply (Sherwood & Hanson, 2008). Given what at first glance appears a hopeless crusade should only serve to increase our resolve.

In looking across these studies a pattern emerges that would seem to provide a potential model for scalable professional development that would be sustainable, personalized, and in accord with the existing infrastructure and sociocultural norms already in wide-spread use across the United States. While many have discussed the global reach and promise of distance education, statistics show that learner preferences for 3.9 million online users in the United States tend to be regionally based, with 85% of learners taking courses from institutions that are within 50 miles of their physical location, or within an adjacent state (The Sloan Consortium, 2008). Couple this preference with the potential efficiencies afforded by brokering differentiated PD through a national portal (Anderson & Olsen, 2006), and what might be a worthwhile approach is a national repository of vetted PD opportunities and resources (both face-to-face and online) that are nationally deployed, but contextualized for local and personal consumption. Institutions of higher education might serve as regional base camps providing the physical tether or lifeline for teachers as they ascend upward on their self-guided and collaborative school-based journey of learning. This regional online approach is not necessarily new, as consortia such as the Western Governors University (WGU) (2009) and the Southern Regional Education Board (SREB) (2009) have provided online offerings for years, but are not currently structured to support the local university reform partnership model whereby:

1. A physical institution is within 50 miles of every teacher.
2. A physical human presence is available on the ground working with every school district.
3. A blended PD approach for learning tightly couples online resources and opportunities to local curricula and student learning.

It would seem that a state-based university network with an agreed upon suite of localized, but common offerings and on-demand modules, accepted between institutions within a state may provide efficiencies in development costs, quality, and standardization, while also permitting flexibility and geographical proximity via the blended PD delivery model (see prelim question 2 for a discussion of blended learning). Universities would form long term relationships with individual school systems within their region. Then working with full time in-school teacher leaders and administrators, as well as with school-wide teams who monitor incremental improvement, we might facilitate durable and significant student learning one classroom and one teacher at a time (Darby, 2008; Elmore, 2004; Fishman, et al., 2003; Fullan, 2007; Hawley & Valli, 1999; WestEd, 2000).

To answer the question, is effectiveness a useful measure to study online PD in science education, I would say yes, but that it depends. It depends on the commitment of administrators, funding, community support, and teacher stakeholder buy-in, as well as the host of other components and resources that determine the potential success of any professional development experience. The structure of the school is a complex one with numerous and diverse ecosystems operating within it (Hewson, 2007). Teacher turnover, school migration, and teaching out of field issues only serve to exacerbate long term school-based reform efforts (Ingersoll, 1999). This said, enculturating PD as part of an on-going professional pursuit of school-wide improvement would seem to instantiate the importance of PD beyond the migration pattern of any individual teacher, and facilitate school cohesion of PD efforts over time. School-based reform PD might also create a structure that transitory teachers may plug-into upon entering a new school.

In closing, PD effectiveness is a relative term that needs to be defined for each local context and school in which an on-going PD effort is in process and needs to be articulated in cooperation with the teachers working within the school where the reform is occurring (Elmore, 2004; Fishman, et al., 2003; WestEd, 2000). To say we should not attempt to measure the effectiveness our of PD efforts because it is an arduous task is misguided and ill-informed. The primary goal of all PD in science education is to improve student learning by way of empowering teachers to be more effective in their classrooms. Given the future prosperity of our own sons and daughters chance for success and personal independence is what is at stake, failing to measure the effectiveness of our PD efforts, however challenging, is unconscionable. We just need to be cognizant of the realities we face and realize that teacher and student improvement is a slow, expensive, and complex process, and not one that will be solved by any single PD experience (online or otherwise). Online teacher PD is but one critical piece of the PD landscape which may provide efficiencies of scale and scope, granting access to resources, tools, colleagues, opportunities, and expertise that might not otherwise be available. As such, its affordances should be appropriately assessed and blended within the local face-to-face needs in which it is employed.

Figure Captions

Figure 1. LSC theory of action. Depicted in Banilower, E.R., Heck, D. J., & Weiss, I.R. (2007). Can professional development make the vision of the standards a reality? The impact of the national science foundation's local systemic change through teacher enhancement initiative. *Journal of Research in Science Teaching, 44*(3), 375-395.

Figure 2. Logic model of the impact of professional development on student achievement. Depicted in Garet, M., Porter, A., Desimone, L., Birman, B., & Yoon, K. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal, 38*(4), 915-945.

Figure 3. Model of Teacher Learning. Depicted in Fishman, B. J., Marx, R. W., Best, S., & Tal, R. T. (2003). Linking teacher and student learning to improve professional development in systemic reform. *Teaching and Teacher Education, 19*(6), 643-658.doi: 10.1016/S0742-051X(03)00059-3

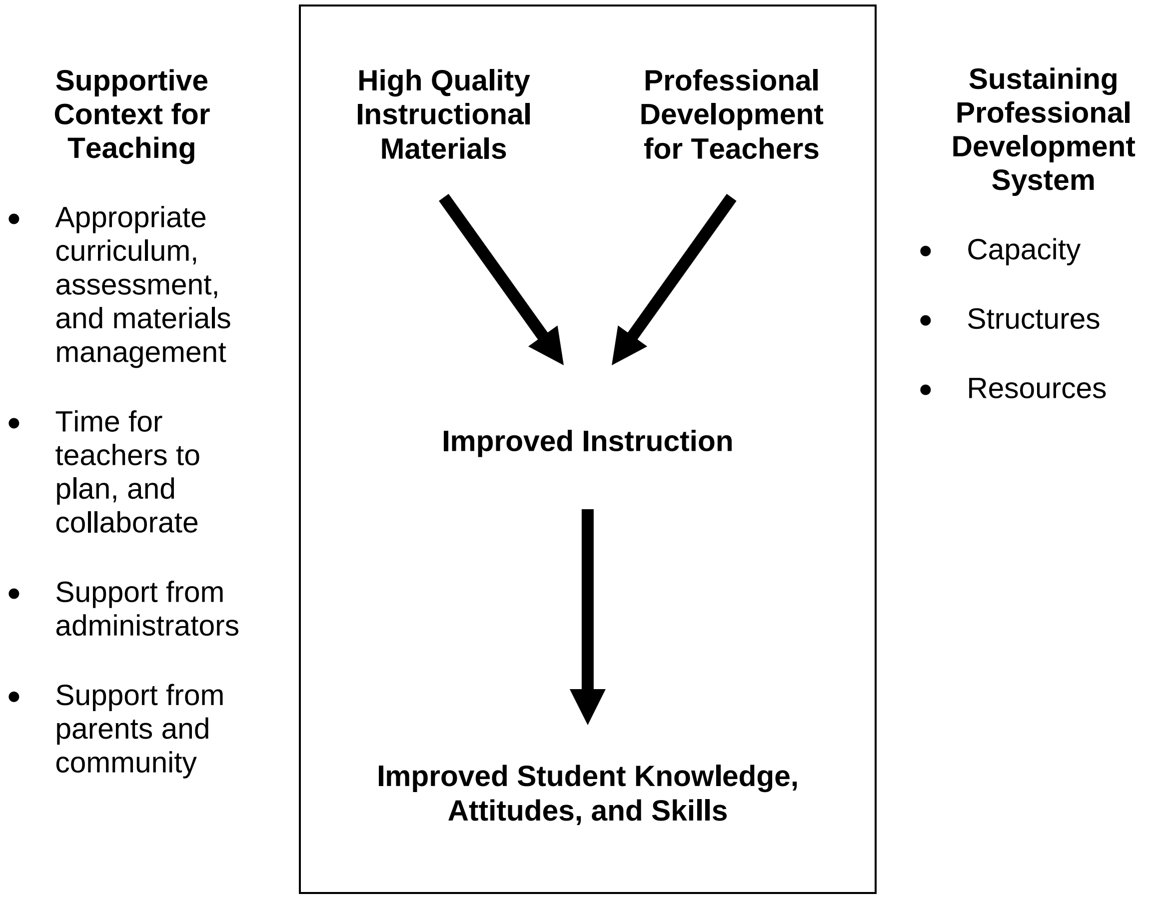


*Figure 1. LSC theory of action*

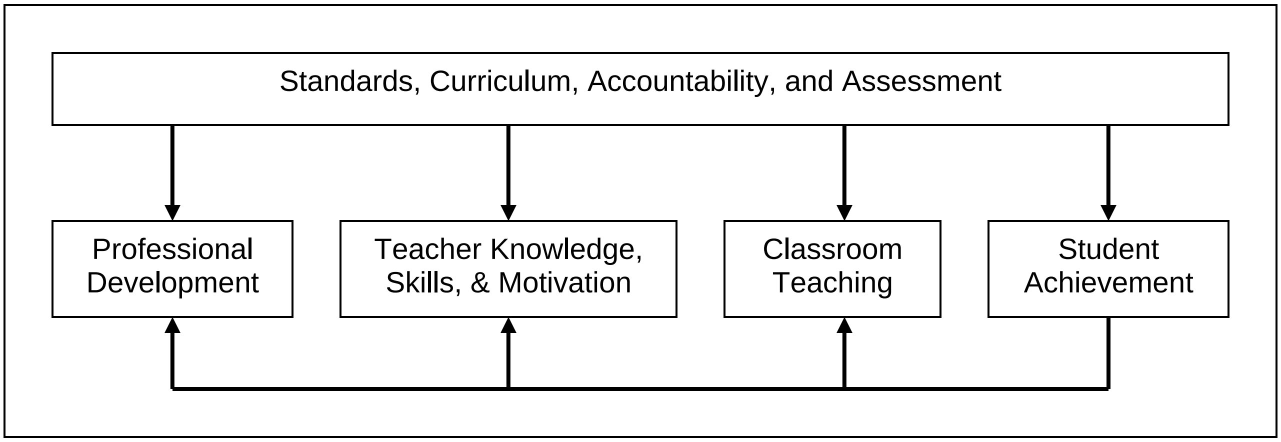


*Figure 2. Logic model of the impact of professional development on student achievement*

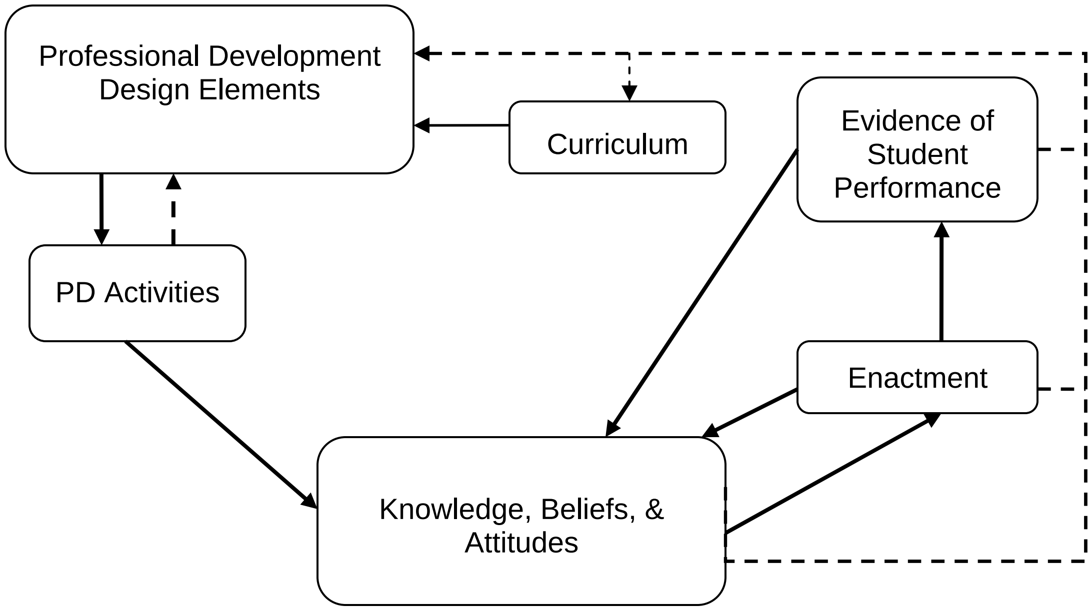


*Figure 3. Model of teacher learning*

Table 1

Professional Development Research Study Comparison

| Research Study | One Independent Variable: PD Delivery Model<br>Example PD Program Models | Target Audience/ Content Area | Example Dependent Variables<br>Teacher Beliefs, Attitudes, Confidence | Teacher Content Knowledge | Teacher PCK* | Classroom Integration Student Learning |
|---|---|---|---|---|---|---|
| | | Face-to-Face PD Approaches | | | | |
| Akerson et al. (2009) | Summer institutes, on-site follow-up | elementary science inquiry and NOS* | • | | • | • |
| Duran et al. (2005) | Summer institutes, on-site follow-up | elementary science content and inquiry | • | • | • | • |
| Fishman et al. (2003) | school-based, weekend workshops, curriculum reform | middle school science and inquiry | • | | • | • |
| Varma et al. (2008) | school-based, mentor, curric. reform | middle and high school science and inquiry | • | | • | • |
| Weinburgh et al. (2008) | Summer institute, on-site coaching | elementary school science and pedagogy | • | • | • | • |
| WestEd (2000) | school-based, professional learning communities, curriculum reform | primarily elementary schools, school-based PD driven by student data | • | • | • | • |
| | | Online PD Approaches | | | | |
| Asbell et al. (2007) | online short courses | middle and high school science content | • | • | • | |
| Harlen et al. (2004) | online short courses | elementary and middle science and inquiry | • | • | • | |
| Krall et al. (2009) | self-paced on-demand, mentor, hands-on kits | elementary and middle science and inquiry | • | • | • | |
| | | Blended PD Approaches | | | | |
| Penuel et al. (2007) | Comparison across 28 PD providers, various models of delivery & support | K-12 science support curriculum integration using technology | • | • | • | • |
| Berger et al. (2008) | 9 once-a-month sessions on-site with simultaneous online discourse | high school science, physics | • | | • | • |
| Owston et al. (2006) | 4 sessions on-site in-between 3 8-week sessions online | middle school science (and math) | • | • | • | • |

NOTE: PCK* is acronym for pedagogical content knowledge and NOS* is acronym for nature of science

References

Akerson, V.L., Flick, L.B., & Lederman, N. G. (2000). The Influence of primary children's ideas in science on teaching practice. *Journal of Research in Science Teaching, 37*(4), 363-385.

Akerson, V.L., Morrison, J.A., & McDuffie, A.R. (2006). One course is not enough: Preservice elementary teachers' retention of improved views of nature of science. *Journal of Research in Science Teaching, 43*(2), 194-213.

Akerson, V.L., Townsend, J., Donnelly, L., Hanson, D., Tira, P., & White, O. (2009). Scientific modeling for inquiring teachers network (SMIT'N): The Influence on elementary teachers' views of nature of science, inquiry, and modeling. *Journal of Science Teacher Education, 20*(1), 21-40.

Albert Shanker Institute (2002). Bridging the gap between standards and achievement: The imperative for professional development in education. Washington, DC: Elmore, R.

America Competes Act (2007).

American Association for the Advancement of Science (1993). *Benchmarks for science literacy*. New York, NY: Oxford University Press.

Anderson, L., & Olsen, B. (2006). Investigating early career urban teachers' perspectives on and experiences in professional development. *Journal of Teacher Education, 57*(4), 359-377.

Appleton, K. (2002). Science activities that work: Perceptions of primary school teachers. *Research in Science Education, 32*(3), 393-410.

Appleton, K. (2007). Elementary science teaching. In S.K. Abell & N. G. Lederman (Eds.), *Handbook of Research on Science Education* (pp. 493-535). Mahwah, NJ: Lawrence Erlbaum Associates.

Asbell-Clarke, J., & Rowe, E. (2007). Learning science online: A descriptive study of online science courses for teachers. *Journal of Asynchronous Learning Networks, 11*(3), 95-121.

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review, 84*(2), 191-215.

Banilower, E.R., Heck, D. J., & Weiss, I.R. (2007). Can professional development make the vision of the standards a reality? The impact of the national science foundation's local systemic change through teacher enhancement initiative. *Journal of Research in Science Teaching, 44*(3), 375-395.

Barab, S. A., Barnett, M., & Squire, K. (2002). Developing an empirical account of a community of practice: Characterizing the essential tensions. *The Journal of the Learning Sciences, 11*(4), 489-542.

Barab, S., The ILF Design Team, Makinster, J.G., Moore, J.A., & Cunningham, D.J. (2001). Designing and building an on-line community: The struggle to support sociability in the inquiry learning forum. *Educational Technology Research & Development, 49*(4), 71-96.

Barnett, M. (2002). *Issues and trends concerning electronic networking technologies for teacher professional development: A critical review of the literature.* Paper presented at the American Educational Research Association, New Orleans.

Berger, H., Eylon, B-S., & Bagno, E. (2008). Professional development of physics teachers in an evidence-based blended learning program. *Journal of Science Education & Technology, 17*(4), 399-409.

Blumenfeld, P., Fishman, B. J., Krajcik, J., Marx, R. W., & Soloway, E. (2000). Creating usable innovations in systemic reform: Scaling up technology-embedded project-based science in urban schools. *Educational Psychologist, 35*(3), 149-164.

Borko, H. (2004). Professional development and teacher learning: Mapping the terrain. [Scholarly-Academic]. *Educational Researcher, 33*(8), 3-15.

Bransford, J.D., Brown, A. L., Cocking, R.R., Donovan, M.S., & Pellegrino, J.W. (Eds.). (2000). *How people learn: Brain, mind, experience, and school*. Washington, D.C.: National Academy Press.

Brickhouse, N.W. (1990). Teachers' beliefs about the nature of science and their relationship to classroom practice. *Journal of Teacher Education, 41*(3), 53-62.

Briscoe, C., & Peters, J. (1997). Teacher collaboration across and within schools: Supporting individual change in elementary science teaching. *Science Education, 81*(1), 51-65.

Brown, D.E. (1992). Using examples and analogies to remediate misconceptions in physics: Factors influencing conceptual change. *Journal of Research in Science Teaching, 29*(1), 17-34.

Brown, D.E., & Clement, J. (1989). Overcoming misconceptions via analytical reasoning: Abstract transfer versus explanatory model construction. *Instructional Science, 18*, 237-261.

Bryan, L.A., & Abell, S.K. (1999). Development of professional knowledge in learning to teach elementary science. *Journal of Research in Science Teaching, 36*(2), 121-139.

Buzhardt, J., Greenwood, C., Abbott, M., & Tapia, Y. (2006). Research on scaling up evidence-based instructional practice: Developing a sensitive measure of the rate of implementation. *Educational Technology Research & Development, 54*(5), 467-492.

Cuban, Larry (1990). Reforming again, again, and again. *Educational Researcher, 19*(1), 3-13.

Czerniak, C., & Lumpe, A. (1996). Relationship between teacher beliefs and science education reform. *Journal of Science Teacher Education, 7*(4), 247-266.

Darby, A. (2008). Teachers' emotions in the reconstruction of professional self-understanding. *Teaching and Teacher Education, 24*(5), 1160-1172.

Darling-Hammond, L., & McLaughlin, M.W. (1995). Policies that support professional development in an era of reform. *Phi Delta Kappan, 76*(8), 597-604.

Dede, C. (2006). The evolution of online teacher professional development. In C. Dede (Ed.), *Online professional development for teachers: Emerging models and methods* (pp. 1-11). Cambridge, MA: Harvard Education Press.

Dede, C., Ketelhut, D.J., Whitehouse, P., Briet, L., & McCloskey, E. (2009). A research agenda for online teacher professional development. *Journal of Teacher Education, 60*(1), 8-19.

del Valle, R., & Duffy, T. (2009). Online learning: Learner characteristics and their approaches to managing learning. *Instructional Science, 37*(2), 129-149.

Dick, W., Carey, L., & Carey, J.O. (2008). *The systematic design of instruction* (7th ed.). Upper Saddle River, NJ: Merrill.

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23*(7), 5-12.

Driver, R., Guesne, E., & Tiberghien, A. (2000a). Children's ideas and the learning of science. In R. Driver, E. Guesne & A. Tiberghien (Eds.), *Children's ideas in science* (pp. 1-9). Philadelphia, PA: Open University Press.

Driver, R., Guesne, E., & Tiberghien, A. (2000b). Some features of children's ideas and their implications for teaching. In R. Driver, E. Guesne & A. Tiberghien (Eds.), *Children's ideas in science* (pp. 193-201). Philadelphia, PA: Open University Press.

Druva, C.A., & Anderson, R.D. (1983). Science teachers' characteristics by teacher behavior by student outcomes. *Journal of Research in Science Teaching, 20*(5), 467-479.

Duran, E., & Duran, L. B. (2005). Project ASTER: A model staff development program and its impact on early childhood teachers' self-efficacy. *Journal of Elementary Science Education, 17*(2), 1-12.

Economic Policy Institute (2003). Teacher quality: Understanding the effectiveness of teacher attributes (pp. 64). Washington, D.C.: Rice, J.K.

Elmore, R. F. (2004). *School reform from the inside out: Policy, practice and performance*. Cambridge, MA: Harvard Education Press.

Feiman-Nemser, S. (2001). From preparation to practice: Designing a continuum to strengthen and sustain teaching. *Teachers College Record, 103*(6), 1013-1055.

Feiman-Nemser, S., & Parker, M. B (1990). Making subject matter part of the conversation or helping beginning teachers learn to teach. *Journal of Teacher Education, 41*(3), 32-44.

Fishman, B. J., Marx, R. W., Best, S., & Tal, R. T. (2003). Linking teacher and student learning to improve professional development in systemic reform. *Teaching and Teacher Education, 19*(6), 643-658.

Fullan, M. (2007). Change the terms for teacher learning. *The Journal of Staff Development, 28*(3), 35-36.

Fullan, M., & Miles, M.B. (1992). Getting reform right: What works and what doesn't. *Phi Delta Kappan, 73*(10), 744-752.

Garet, M., Porter, A., Desimone, L., Birman, B., & Yoon, K. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal, 38*(4), 915-945.

Glasson, G. E., & Lalik, R.V. (1993). Reinterpreting the learning cycle from a social constructivist perspective: A qualitative study of teachers' beliefs and practices. *Journal of Research in Science Teaching*, *32*(2), 187-208.

Goldhaber, D., & Anthony, E. (2007). Can teacher quality be effectively assessed? National board certification as a signal of effective teaching. *The Review of Economics and Statistics, 89*(1), 134-150.

Goldhaber, D.D., & Dominic, J.B. (2000). Does teacher certification matter? High school teacher certification status and student achievement. *Educational Evaluation and Policy Analysis, 22*(2), 129-145.

Guskey, T. R. (1986). Staff development and the process of teacher change. *Educational Researcher, 15*(5), 5-12.

Guskey, T. R. (2000). *Evaluating professional development*. Thousand Oaks, CA: Corwin Press.

Guskey, T. R. (2003). What makes professional development effective? *Phi Delta Kappan*, *84*(10), 748-750.

Hanuscin, D.L., & Lee, M.H. (2008). Using the learning cycle as a model for teaching the learning cycle to preservice elementary teachers. *Journal of Elementary Science Education, 20*(2), 51-66.

Harlen, W, & Doubler, S. J. (2004). Can teachers learn through enquiry on-line? Studying professional development in science delivered on-line and on-campus. *International Journal of Science Education*, *26*(10), 1247 - 1267.

Harlen, W. (1997). Primary teachers' understanding in science and its impact in the classroom. *Research in Science Education*, *27*(3), 323-337.

Harlen, W. (2004). Evaluating inquiry-based science developments.

Hawley, W.D., & Valli, L. (1999). The essentials of effective professional development: A new consensus. In L. Darling-Hammond & G. Sykes (Eds.), *Teaching as the learning profession: Handbook of policy and practice* (pp. 127-150). San Francisco, CA: Jossey-Bass.

Hewson, P.W. (2007). Teacher professional development in science. In S.K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 1179-1203). Mahwah, NJ: Lawrence Erlbaum Associates Publishers.

Heywood, D. S. (2007). Problematizing science subject matter knowledge as a legitimate enterprise in primary teacher education. *Cambridge Journal of Education, 37*(4), 519-542.

Horizon Research (2001). *Report of the 2000 national survey of science and mathematics education* (No. REC-9814246). Chapel Hill, NC: Weiss, I.R., Banilower, E.R., McMahon, K.C., & Smith, S.P. .

Horizon Research (2002). *Status of elementary school science teaching*. Chapel Hill, NC: Fulp, S. .

Horizon Research (2003). *Looking inside the classroom: A study of K-12 mathematics and science education in the United States*. Chapel Hill, NC: Weiss, I.R., Pasley, J.D., Smith, P.S., Banilower, E.R. & Heck, D.J. .

Horizon Research (2006). *Lessons from a decade of mathematics and science reform: A capstone report for the local systemic change through teacher enhancement initiative* (No. NSF RED-9255369). Chapel Hill, NC: Banilower, E.R., Boyd, S.E.., Pasley, J.D., & Weiss, I.R. .

Howitt, C. (2007). Pre-Service elementary teachers' perceptions of factors in an holistic methods course influencing their confidence in teaching science. *Research in Science Education, 37*(1), 41-58.

Hur, J.W., & Brush, T.A. (2009). Teacher participation in online communities: Why do teachers want to participate in self-regulated online communities of K-12 Teachers? *Journal of Research on Technology in Education, 41*(3), 279-303.

Ingersoll, R. (1999). The problem of underqualfied teachers in American secondary schools. *Educational Researcher, 28*(2), 26-37.

Jones, M.G., & Carter, G. (2007). Science teacher attitudes and beliefs. In S.K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 1067-1104). Mahwah, NJ: Lawrence Erlbaum Associates.

Kang, N. (2007). Elementary teachers' epistemological and ontological understanding of teaching for conceptual learning. *Journal of Research in Science Teaching, 44*(9), 1292-1317.

Kennedy, M. M. (1998). *Form and substance in inservice teacher education* (No. RED-9452971): University of Wisconsin-Madison. National Institute for Science Education. .

Krall, R.M., Straley, J.P., Shafer, S.A., & Osborn, J.L. (2009). Hands-on at a distance: Evaluation of a temperature and heat distance learning course *Journal of Science Education & Technology, 18*(2), 173-186.

Lee, C.A., & Houseal, A. (2003). Self-efficacy, standards, and benchmarks as factors in teaching elementary school science. *Journal of Elementary Science Education, 15*(1), 37-55.

Lee, O. (1995). Subject matter knowledge, classroom management, and instructional practices in middle school science classrooms. *Journal of Research in Science Teaching, 32*(4), 423-440.

Linn, M.C. (2006). WISE teachers: Using technology and inquiry for science instruction. In E.A. Ashburn & R.E. Floden (Eds.), *Meaningful learning using technology* (pp. 45-69). Danvers, MA: Columbia University.

Locks-Horsley, S., Stiles, K., & Hewson, P. W. (1996). Principles of effective professional development for mathematics and science education: A synthesis of standards. *National Institute for Science Education Brief, 1*(1), 1-6.

Loucks-Horsley, S. (1999). Research on professional development for teachers of mathematics and science: The state of the scene. *School Science and Mathematics*, *99*(5), 258-270.

Lowes, S., Peiyi, L., & Yan, W. (2007). Studying the effectiveness of the discussion forum in online professional development courses. *Journal of Interactive Online Learning*, *6*(3), 181-210.

Luera, G. R. (2005). What type and level of science content knowledge of elementary education students affect their ability to construct an inquiry-based lesson. *Journal of Elementary Science Education, 17*(1), 12-25.

McLoughlin, C., & Lee, M.J.W. (2008). Future learning landscapes: Transforming pedagogy through social software. *Innovate: Journal of Online Education*, *4*(5). Retrieved from http://www.innovateonline.info/index.php?view=article&id=539&action=synopsis

Milman, N.B., & Kilbane, C.R. (2005). Digital teaching portfolios: Catalysts for fostering authentic professional development. *Canadian Journal of Learning and Technology*, *31*(3).

Monk, D.H. (1994). Subject area preparation of secondary mathematics and science teachers and student achievement. *Economics of Education Review, 13*(2), 125-145.

Moore, M.G. (1993). Theory of transactional distance. In D. Keegan (Ed.), *Theoretical principles of distance education* (pp. 23-38). New York, NY: Routledge.

Morine-Dershimer, G., & Kent, T. (1999). The complex nature and sources of teachers' pedagogical knowledge. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (Vol. 6, pp. 21-50). Boston, MA: Kluwer Academic Publishers.

Munck, M. (2007). Science pedagogy, teacher attitudes, and student success. *Journal of Elementary Science Education, 19*(2), 13-24.

National Bureau of Economic Research (2007). *Teacher credential and student achievement in high school: A cross-subject analysis with student fixed effects* (No. 13617. JEL No. I21,J45). Cambridge, MA: Clotfelter, C.T., Ladd, H.F., & Vigdor, J.L.

National Bureau of Economic Research (2008). *The narrowing gap in New York city teacher qualification and its implications for student achievement in high-poverty schools* (No. 14021. JEL No. I21,J24,J45). Cambridge, MA: Boyd, D., Lankford, H., Loeb, S., Rockoff, J., Wyckoff, J.

National Research Council (1996). *National Science Education Standards*. Washington, D.C.: National Academy Press.

National Research Council (2007). *Enhancing professional development for teachers: Potential uses of information technology. Report of a workshop*. Washington, DC: Committee on Enhancing Professional Development for Teachers, National Academies Teacher Advisory Council. Center for Education, Division of Behavioral and Social Sciences and Education.

National Staff Development Council (2008). *Professional learning in the learning profession: A status report on teacher development in the U.S. and abroad*. Dallas, TX: Wei, R.C., Darling-Hammond, L., Andree, A., Richardson, N., & Orphanos, S.

Nespore, J. (1987). The role of beliefs in the practice of teaching. *Curriculum Studies, 19*(4), 317-238.

Overbaugh, R., & Lu, R. (2008). The impact of a NCLB-EETT funded professional development program on teacher self-efficacy and resultant implementation. *Journal of Research on Technology in Education, 41*(1), 43-61.

Owston, R.D., Sinclair, M., & Wideman, H. (2006). *Evaluation of a blended professional development program for middle-school mathematics and science teachers.* Paper presented at the American Educational Research Association Annual Meeting. from http://www.edu.yorku.ca/*rowston/AERA06.pdf

Pajares, M.F. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. *Review of Educational Research, 62*(3), 307-332.

Parker, J. (2004). The synthesis of subject and pedagogy for effective learning and teaching in primary science education. *British Educational Research Journal, 30*(6), 819-839.

Penuel, W.R., Fishman, B.J., Yamaguchi, R., & Gallagher, L.P. (2007). What makes professional development effective? Strategies that foster curriculum implementation. *American Educational Research Journal, 44*(4), 921-958.

Penuel, W.R., & Means, B. (2004). Implementation variation and fidelity in an inquiry science program: Analysis of GLOBE data reporting patterns. *Journal of Research in Science Teaching, 41*(3), 294-315.

Plourde, L. A. (2002). The influence of student teaching on preservice elementary teachers' science self-efficacy and outcome expectancy beliefs. *Journal of Instructional Psychology, 29*(4), 245.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Towards a theory of conceptual change. *Science Education, 66*(2), 211-227.

Rivkin, S.G., Hanushek, E.A., & Kain, J.F. (2005). Teachers, schools, and academic achievement. *Econometrica, 73*(2), 417-458.

RMC Research Corporation, & Center on Instruction (2008). *Effective Science Instruction: What does research tell us*. Portsmouth, NH: Banilower, E.R., Cohen, K., Pasley, J.D., & Weiss, I. .

Schlager, M.S., & Fusco, J. (2003). Teacher professional development, technology, and communities of practice: Are we putting the cart before the horse? In S. Barab, R. Kling & J. Gray (Eds.), *Designing for virtual communities in the service of learning* (pp. 203-220): Cambridge University Press.

Schmidt, W.H., & Buchman, M. (1983). Six teachers' beliefs and attitudes and their curriculum time allocations. *The Elementary School Journal, 84*(2), 162-171.

Shallcross, T., Spink, E., Stephenson, P., & Warwick, P. (2002). How primary trainee teachers perceive the development of their own scientific knowledge: Links between confidence, content and competence? *International Journal of Science Education, 24*(12), 1293-1312.

Sherman, G., & Byers, A. (in press). Electronic portfolios in the professional development of educators. In D.J. Phillip (Ed.), *Portfolios and global diffusion: Solutions for collaborative education.*

Sherwood, R. D., & Hanson, D. L. (2008). A Review and analysis of the NSF portfolio in regard to research on science teacher education. *Electronic Journal of Science Education*, *12*(1), 20-38.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1-22.

Signer, B. (2008). Online professional development: combining best practices from teacher, technology and distance education. *Journal of In-Service Education, 34*(2), 205-218.

Simmons, P.E., Emory, A., Carter, T., Coker, T., Finnegan, B., Crockett, D., et al. (1999). Beginning teachers: Beliefs and classroom actions. *Journal of Research in Science Teaching*, *36*(8), 930-954.

Simon, S., & Johnson, S. (2008). Professional learning portfolios for argumentation in school science. *International Journal of Science Education, 30*(5), 669-688.

Southern Region Education Board (2009). About SREB Retrieved May 22, 2009, from http://www.sreb.org/main/SREB/index.asp

Supovitz, J.A., & Turner, H.M. (2000). The effects of professional development on science teaching practices and classroom culture. *Journal of Research in Science Teaching, 37*(9), 963-980.

The Education Arcade, & Massachusetts Institute of Technology (2009). *Moving learning games forward: Obstacles, opportunities, and openness*. Cambridge, MA: Klopfer, E., Osterweil, S., & Salen, K.

The Sloan Consortium (2008). *Staying the course: Online education in the United States, 2008*. Newburyport, MA: Allen, I.E., & Seaman, J. .

The Western Governors University (2009). About WGU Retrieved May 20, 2009, from http://www.wgu.edu/about_WGU/overview

Tobin, K., & Fraser, B.J. (1990). What does it mean to be an exemplary science teacher? *Journal of Research in Science Teaching, 27*(1), 3-25.

U.S. Department of Education (2000). Does professional development change teaching practice? Results from a three-year study. Washington, DC: Porter, A., Garet, M.S., Disimone, L., Yoon, K.S., & Birman, B.F.

U.S. Department of Education, Institute of Education Sciences, & National Center for Education Evaluation and Regional Assistance (2008). *Examining context and challenges in measuring investment in professional development: A case study of six school districts in the southwest region* (No. REL 2008-No.037). Washington, DC: Chambers, J. G. , Lam, I., Mahitivanichcha, K.

US Department of Education, Institute of Education Sciences, National Center for Education Evaluation and Regional Assistance, & Regional Educational Laboratory Southwest (2007). *Reviewing the evidence on how teacher* *professional development affects student achievement: Issues and answers* (No. REL 2007-No. 033). Washington, D.C.: Yoon, K. S., Duncan, T., Lee, S.W., Scarloss, B. & Shapley, K. .

Varma, K., Husic, F., & Linn, M.C. (2008). Targeted support for using technology-enhanced science inquiry modules. *Journal of Science Education & Technology, 17*(4), 341-356.

Wayne, A.J., Yoon, K. S., Zhu, P., Cronen, S., & Garet, M. S. (2008). Experimenting with teacher professional development: Motives and methods. *Educational Researcher, 37*(8), 469-479.

Wayne, Andrew J., & Youngs, Peter (2003). Teacher characteristics and student achievement gains: A review. *Review of Educational Research, 73*(1), 89-122.

Weinburgh, M., Smith, K., & Clark, J. (2008). Using the reflective teaching model in a year-long professional development: A case study of a second year urban elementary teacher. *Electronic Journal of Science Education, 12*(2), 22-40.

Wenner, G. (1993). Relationship between science knowledge levels and beliefs toward science instruction held by preservice elementary teachers. *Journal of Science Education & Technology, 2*(3), 461-468.

WestEd (2000). *Teachers who learn, kids who achieve: A look at schools with model professional development*. San Francisco, CA.

Whitehurst, G.J. (2002). *Research on teacher preparation and professional development*. Paper presented at the White House Conference on Preparing Tomorrow's Teachers. Retrieved January 28, 2009, from http://www.ed.gov/admins/tchrqual/learn/preparingteachersconference/whitehurst.html

Wilson, S. M., Floden, R.E., & Ferrini-Mundy, J. (2002). Teacher preparation research: An insider's view from the outside. *Journal of Teacher Education*, *53*(3), 190-204.

Xu, J. (2003). Promoting school-centered professional development through teaching portfolios. *Journal of Teacher Education, 54*(4), 347-361.

Yerrick, R. , Parke, H., & Nugent, J. (1997). Struggling to promote deeply rooted change: The "filtering effect" of teachers' beliefs on understanding transformational views of teaching science. *Science Education, 81*(2), 137-159.

Yoon, K.S., Duncan, T., Lee, S.W., & Shapley, K. (2008). *The effects of teachers' professional development on student achievement: Findings from a systematic review of evidence*. Paper presented at the American Educational Research Association Annual Meeting.