Question 3: Discuss the literature on the influence of pedagogical knowledge and pedagogical content knowledge on student learning and teacher instruction in science in elementary classrooms

In addressing this question about unique differences between pedagogy and pedagogical content knowledge it may make sense to take a brief historical look back over the last several decades of educational reform, which include student achievement rankings compared with other countries. This will provide a rich backdrop that will help explicate the unique differences between pedagogical knowledge and pedagogical content knowledge and their respective impact on student learning and teacher instruction. Coupling theoretical advances in educational psychology and learning theory will also provide an essential background context regarding their impact on classroom practice.

A Thirty Year Retrospective on U.S. Educational Reform

Looking back historically from a policy perspective, since *A Nation at Risk* was published in 1983 focusing on high school reform calling for more instructional hours, there has been an ongoing focus on mathematics and science education in our country (U.S. Department of Education, 1983). In 1985, we saw the launch of Project 2061 by the American Association for the Advancement of Science, emphasizing the need for scientific literacy for all Americans with the publication in 1993 of the national science education benchmarks for science (American Association for the Advancement of Science, 1993). These efforts were followed in 1991 by the National Science Foundation's (NSF) Statewide Urban and Rural Systemic Initiatives that focused on improving K-12 science and math education in large part through enhancing teacher instruction in the classroom at either the state or district level (SRI International, 1998). Then just a few years later, President Bill Clinton signed into law the Goals 2000: Educate America

Act that included the challenge of making America first in math and science student achievement by the year 2000 ("Goals 2000: Educate America Act ", 1994). This reform law included a major component for teacher education and professional development to increase student achievement in mathematics and science at the elementary school level. In 1996, the National Research Council (NRC) released the *National Science Education Standards,* which espoused not only science content standards, but inquiry-based instruction as both a content and process standard, and included professional development standards to support its reform implementation (National Research Council, 1996). The National Commission on Teaching and America’s Future released a seminal report during the same year calling for drastic reform to improve and empower our nation’s teachers, schools and classrooms (National Commission on Teaching and America's Future, 1996). In 2000, the National Commission on Mathematics and Science Teaching for the 21^{st} Century released its report, *Before It’s Too Late*, calling for increased support for science and mathematics education through improving teacher competence (U.S. Department of Education, 2000). We then saw the No Child Left Behind Act of 2001 and in 2007 the report “Rising Above the Gathering Storm” that supported teacher professional development in mathematics and science education (2007). Most recently the passage of the America Competes Act of 2007 also has major funding allocations for increasing the quality of teachers through professional development. Thus, numerous attempts have been made by the Federal government to coordinate all Federal expenditures on science education over the last several decades with attempts to improve classroom instruction through teacher enhancement of knowledge, attitudes, and skills, with negligible (Elmore, 2004; M. G. Jones & Carter, 2007), or possibly deleterious effects at the elementary level (Griffith, 2008). While progress has been made on the policy front, such as the establishment of national science education standards and an increased focus on accountability, U.S. students collectively appear to under-perform when compared with their international counterparts in science and leave ample room for growth at the proficiency level on standardized comparisons over time within the United States. A more detailed review of national student achievement will support the need for improved classroom instruction through effective pedagogical strategies that facilitate improved student learning.

Review of Student Achievement

A review of the National Assessment of Educational Progress (NAEP) reports student achievement in science and mathematics for grades four, eight, and twelve in one of four categories: (a) “Below Basic,” (b) “Basic,” (c) “Proficient,” or (d) “Advanced.” In 2005, NAEP reported that only 29% of both fourth and eighth grade students performed at or above the proficient level in science, where proficient represents solid academic performance and demonstrated competency of challenging subject matter (U.S. Department of Education, 2006). This follows a similar pattern for the 2000 NAEP scores as well. Unfortunately, regardless of minor increases in NAEP mathematics scores since the 1970s, students’ performance in science has remained nearly stagnant across fourth and eighth grade proficiency levels, negative for science at grade twelve, and disappointing across all grade levels for nearly 30 years (U.S. Department of Education, 2000, 2006).

From an international perspective, we may look at the 1999 Trends in International Mathematics and Science Study (TIMMS) developed and administered since 1995 by International Association for the Evaluation of Educational Achievement. This instrument gathers student assessment data from dozens of nations, and seeks to broadly compare student performance in mathematics and science in grades four and eight. In science both content and cognitive ability is evaluated (U.S. Department of Education, National Center for Education

Statistics, & Institute of Education Sciences, 2008). In 1999 the United States performed at approximately the same level as our international peers for fourth grade but by twelfth grade the United States was last among the 20 participating nations assessed in advanced math and physics (National Academy of Sciences, et al., 2007). More recent 2007 TIMMS data are not considerably better. Comparing data from over 36 countries at the fourth grade level and 48 countries at the eighth grade level the United States shows no significant differences over the 1995 rankings across both grades. From a benchmarking perspective, compared against the 19 other countries that participated in the previous 1995 TIMSS, the United States has shown zero growth, while at the eighth grade level five other nations demonstrated improvement. The United States ranked eleventh behind Singapore, Chinese Taipei, Japan, Korea, England, Hungary, Czech Republic, Slovenia, Hong Kong, and the Russian Federation respectively, when comparing the overall ranking averages of student scores for eighth grade science, with 10 of these nations having significantly higher scores. For fourth grade the United States ranked eighth overall in science behind Singapore, Chinese Taipei, Hong Kong, Japan, Russian Federation, Latvia, and England. But all is not without hope. Both the fourth and eighth grade rankings are above the TIMMS overall average score of 500, and from a statistical standpoint only four nations did significantly better then the United States in the 2007 results for grade four (U.S. Department of Education, et al., 2008). Unfortunately, this single glimmering statistic does not outshine the otherwise less then stellar results that are corroborated on other international measures as well.

Results collected in 2003 by the Organization for Economic Co-operation and Development (OECD)’s Programme for International Student Assessment (PISA) instrument across 41 nations and 275,000 students show that American 15-year olds are near the bottom in their ability to apply mathematical reasoning and problem solving skills, and 17-years olds have remained stagnant for years. The most recent 2006 PISA focused on science content, specifically within the domain of environmental science, and sought to evaluate 15 year olds ability to not just recall or recognize scientific theories and facts, but through open constructed responses, also evaluate students' ability to apply conceptual understanding and skills that should be part of all scientifically literate citizen's repertoire as they make informed decisions concerning science that is relevant to their lives (Bybee, 2008; Organization for Economic Co-operation and Development, 2007). It reported that the United States ranked below the top 20 countries from among the 53 nations participating in the study (i.e., the US ranked 29 out of 53), and scored below the overall PISA average for student performance at a significant level (Organization for Economic Co-operation and Development, 2007).

Thus, across all these comparisons, it would seem safe to say there is room for improvement. This brief review of student achievement is warranted as it may provide a window into the impact of classroom instructional practice, which ultimately as many researchers now agree, is significantly linked to teacher quality as defined by their knowledge and ability to apply subject matter and pedagogical content knowledge related to the subjects they teach (Bransford, Brown, Cocking, Donovan, & Pellegrino, 2000; Clermont & Borko, 1994; Darling-Hammond, 2006; Economic Policy Institute, 2003; D. Goldhaber, 2002; D. Goldhaber & Brewer, 1998; O. Lee, 1995; Mestre & Cocking, 2002; Monk, 1994; Mundry, 2005; National Center for Research on Teacher Education, 1990; National Commission on Teaching and America's Future, 1996; The Council of Chief State School Officers, 2007; Weinburgh, Smith, & Clark, 2008; Whitehurst, 2002; Wilson, Floden, & Ferrini-Mundy, 2002). Unfortunately, there appears to be a lack of coherence between the policy focus and results as reflected in student science and mathematics achievement, and as such, the urgency is now placing the focus on teacher improvement (National Academy of Sciences, et al., 2007; U.S. Department of Education, 2000). Could teachers' pedagogy and pedagogical content knowledge in part be responsible for the plateau in our country's student achievement? While it is beyond the scope of this narrative to empirically address this question, it does provide an intriguing backdrop with which to begin to define the differences between pedagogy and pedagogical content knowledge related to science education and elementary education.

Pedagogical Knowledge versus Pedagogical Content Knowledge

No discussion of pedagogy and pedagogical content knowledge could ensue without referencing Dr. Lee S. Shulman, who in 1986 published his seminal work in Educational Research titled: Those Who Understand: Knowledge Growth in Teaching. In this paper Shulman argued that the large body of education research over the last several decades focused almost exclusively on generic pedagogical research defined as classroom management techniques and non-discipline specific instructional strategies that are now classified as "process-product" research at the near exclusion of content knowledge pedagogy within specific domains such as science, literature, or mathematics (W. Carlsen, 1999; Gess-Newsome, 1999a; Shulman, 1986). In this striking review Shulman argued against the plethora of behaviorist-centric experimental research that presented a sterilized view of the classroom, where the knowledge of classroom pedagogy was detached from actual classroom practice and more importantly, devoid of any linkage to the content knowledge it is designed to support (1986). He argued that pedagogy and content should not be two separate entities, and redefined content knowledge into three categories: (a) subject matter content knowledge, (b) pedagogical content knowledge and, (c) curricula knowledge. Subject matter knowledge was then further refined into either substantive or syntactic knowledge, where Shulman referenced prior work to support the notion of a structural understanding of subject matter. Substantive knowledge deals with the an understanding of how the theories, principles, concepts and facts are organized into a conceptual framework, while syntactic subject matter knowledge deals with the nature of how knowledge is constructed, vetted, accepted, and dispelled within the discipline, i.e., the nature of science (Lederman, 1992; Rigden, 1983; Shulman, 1986). Pedagogical content knowledge (PCK) Shulman claimed should incorporate the awareness and appropriation of analogies, metaphors, examples, demonstrations and explanations unique to the specific content domains as well as knowledge of inherent challenges in learning unique subject matter depending on the topic and students' ages and abilities (1986). Finally, curricular knowledge was defined as necessary awareness of the variety of programs available to support teaching particular subjects at various grade levels (Shulman, 1986). Since this time there have been refinements and expansions to Shulman's early model, which to this day guide conceptual development research in the teaching profession (Abell, 2007; Magnusson, Krajcik, & Borko, 1999; Shulman, 1987). The true inspiration of Shulman's conceptual model might be that of the integration between content and pedagogy, which as he eloquently states:

> …the key to distinguishing the knowledge base of teaching lies at the intersection of content and pedagogy, in the capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by the students (Shulman, 1987, p.327).

A more detailed look will be expanded below in the section on pedagogical content knowledge. The notion of pedagogical content knowledge has become widely accepted in the nomenclature of education, but as a theoretical model with broad explanatory power, its fuzziness has garnered alternative views that espouse an integrative model for pedagogy, content knowledge and context versus a transformative singular construct called pedagogical content knowledge (Abell, 2007; Gess-Newsome, 1999a; Morine-Dershimer & Kent, 1999). In light of overlap between certain categories within the PCK conceptual model, the review that follows will attempt to make references across boundaries where appropriate given the malleability of the constructs as espoused in the literature. Pedagogical knowledge will first be addressed.

General Pedagogical Knowledge

General pedagogy as defined by this body of research focused on an epistemological view anchored initially in a behaviorist perspective, and teacher behaviors were thoroughly examined with the goal to classify and quantify those behaviors that increased student achievement as the sole outcome of instruction (Brophy & Good, 1997; Morine-Dershimer & Kent, 1999; K. Tobin & Fraser, 1990; K. Tobin, Tippins, & Gallard, 1994; Turner & Meyer, 2000). Several have reviewed and discussed these research findings from the seventies and eighties with a comprehensive literature review by Brophy and Good (1997) and numerous case studies from the field of science education document exemplary and non-exemplary practices (Penick & Yager, 1983; K. Tobin & Fraser, 1990; K. Tobin & Gallagher, 1987; K. Tobin & Garnett, 1988; K. G. Tobin, Capie, & Bettencourt, 1988). Generally speaking, with the caveat given that the findings are contextually sensitive to different grade levels, subject areas, and classroom contexts, general pedagogy research found positive correlations between the following teacher behaviors and increased student achievement: (a) increased time on content-focused tasks based on observable, measurable objectives; (b) appropriate pacing of instruction that is cognitively appropriate for the level of students engaged and not so cognitively taxing as to encourage student avoidance; (c) communicating clear expectations for classroom interaction and engagement during lessons; (d) teacher monitoring, movement and proximity to students to maintain classroom decorum; (e) use of prior student knowledge, questions and wait time to stimulate engagement, check for understanding, provide feedback and making student thinking visible; and (f) use of individual and collaborative group practice and hands-on inquiry activities coupled with rewards to acquire knowledge through rehearsal, discourse and positive reinforcement (Beeth & Hewson, 1999; Brophy & Good, 1997; K. Tobin, et al., 1994). Explicit sequential steps of instructional strategies when planned through instructional analysis and operationalized objectives form what researchers call direct instruction (Gagne, 1985; Hunter, 1982; Mager, 1983, 1988; Morine-Dershimer & Kent, 1999; Rosenshine, 1995). Direct instruction and the strategies above derive underpinnings from learning theories advanced through behavioral educational psychologists such as B.F. Skinner and E.L. Thorndike (Collins, 2002).

Morine-Dershimer and Kent (1999) submit an updated model of general pedagogical knowledge that seeks to redress the construct since the emphasis by Shulman (1986) and the research community on pedagogical content knowledge. They argue that pedagogy comprises two major components: (a) general pedagogical knowledge and (b) personal pedagogical knowledge, with the former being informed by formal learning and literature, and the later being situated in personal practice, experience, and beliefs (Morine-Dershimer & Kent, 1999). The more formal general pedagogical knowledge is separated into three facets: (a) classroom management and organization, (b) instructional models, and (c) classroom communication and discourse. See Figure 1 for a visual depiction of this revised pedagogical model.

Classroom Management

The classroom management facet has been addressed above, with the exception of more recent studies that have expanded this line of research beyond observing only external behaviors of students and teachers to include both teacher and student cognition and the ways internal awareness (or metacognition) affects learning of content both from the students' view and that of the teacher in facilitating this process as part of the management of the classroom (Peterson, 1988). Metacognition is similarly confirmed in the most recent synthesis of work on the nature of learning that espouse the positive benefit of self-regulation and monitoring one's learning on various tasks through reflection and self-assessment, and its potential for addressing deeper understanding through constructivist and conceptual change learning strategies (Bransford, et al., 2000; Hennessey, 1999).

Instructional Models

The instructional models and strategies facet of general pedagogical knowledge refers to the various alternative forms of instructional engagement available to teachers depending upon the desired instructional goals, student learning outcomes, and content under consideration (Morine-Dershimer & Kent, 1999). Researchers discuss the grade and subject neutrality of these models, their ability to overlap for differentiated instruction, and their application for various learning purposes. Models available support cooperative learning for social interaction through community discourse, information processing for acquiring, organizing and using information to solve problems, metacognitive models for self-regulation, direct instruction for declarative knowledge and learning of sequenced tasks, and reciprocal teaching models that involve expert scaffolding to support ill-structured learning challenges (Brophy & Good, 1997; Joyce, Weil, & Showers, 1992; Palincsar & Brown, 1984; Rosenshine, 1995; Vygotsky, 1978).

Classroom Communication

Finally, the last facet of general pedagogical knowledge described by Morine-Dershimer et al. (1999) is that of classroom discourse. A collective review of the literature substantiates the importance of: (a) being sensitive to the norms and dialogic styles of different cultures; (b) facilitating higher-order questions in the context of problem-based activities; (c) engaging all learners equitably regardless of gender, ethnicity, or perceived cognitive ability; (d) establishing an environment of clearly defined and mutually acceptable patterns of exchange; and (e) facilitating small-group collaborative peer discourse (Beeth & Hewson, 1999; Kelly, 2007; Morine-Dershimer & Kent, 1999). The literature finds that classroom discourse may also be used to adversely control and limit the breadth and depth of discussion from an authoritative view when teachers have a weaker command of the subject matter (W. S. Carlsen, 1992; O. Lee, 1995; Russell, 1983). When this occurs, questions may be more frequent, but of a lower cognitive ability and more factual in nature. Lemke's work confirmed the earlier findings and classified classroom discourse in "both thematic and organizational patterns," finding that students often times have little opportunity to "talk science" (as cited in Kelly, 2007, pp. 445-446). In summary, a rich body of research on the nature and implications of the classroom discourse between teacher-student and student-student inform the general pedagogical nature of science instruction.

Personal Pedagogical Knowledge

Referring to Figure 1, one sees that Personal Pedagogical Knowledge may be organized into the constructs of prior beliefs and perceptions, and personal practical experiences. Beliefs, attitudes, values, perceptions, and personal experiences affect part of a larger belief system that the literature has shown is deeply seated, resistant to change, inconsistent, and one that 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; M. G. Jones & Carter, 2007; C. A. Lee & Houseal, 2003; Morine-Dershimer & Kent, 1999; Munck, 2007; Nespore, 1987; Pajares, 1992; Posner, Strike, Hewson, & Gertzog, 1982; Schmidt & Buchman, 1983; Simmons, et al., 1999; K. Tobin & Fraser, 1990; Wenner, 1993; Yerrick, Parke, & Nugent, 1997). At the elementary teacher level there is a substantial body of historical research that 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 that in large part is still applicable today (Appleton, 2002; Czerniak & Lumpe, 1996; Harlen, 1997; Heywood, 2007; Howitt, 2007; M. G. Jones & Carter, 2007; O. Lee, 1995; Luera, 2005; Shallcross, Spink, Stephenson, & Warwick, 2002). Jones et al. (2007) provide a review of the literature that documents many issues related to teacher attitudes and beliefs which teacher educators and professional development providers may face in overcoming teachers' entrenched epistemological beliefs, as well as the sociocultural influences that can work against the impact of programs (Haney & McArthur, 2002; Stofflett, 1994; Yerrick, et al., 1997). Unfortunately, research has shown that even if one is successful at increasing teachers' self-efficacy and notions about constructivist pedagogy and science content, these changes may be extremely tentative and short lived (Gess-Newsome, 1999b; Glasson & Lalik, 1993; M. G. Jones & Carter, 2007; Simmons, et al., 1999). Bandera provides recommendations for increasing teacher self-efficacy that include positive feedback, successful experiences in the new practice, and opportunities to observe successful implementations of the same practice (as cited in M. G. Jones & Carter, 2007, p. 1085). These recommendations, in part, mirror those of others regarding components of effective professional development that is situated locally in the environment of the school and classroom (Albert Shanker Institute, 2002;

Fullan, 2007; Guskey, 1986). While a more exhaustive review of the voluminous body and variety of research on beliefs could ensue, an adequate treatment related to its import on pedagogy will now permit a discussion of the last facet of personal pedagogy.

Personal experiences throughout individuals' educational lives, which include their formative years attending school, as well as their preparation and inculcation into the teaching profession, affect their epistemology toward teaching as well as their actions in the classroom (Brand & Glasson, 2004; Pajares, 1992). This may be defined this as teachers' "context-specific pedagogical knowledge" (Morine-Dershimer & Kent, 1999, p. 41). As shown in Figure 1, context-specific pedagogical knowledge is forged through self-reflection, commingling one's general pedagogical knowledge and personal pedagogical knowledge, which over time through experience, provide the teacher with an ever increasing ability to appropriately integrate instructional strategies, discourse, materials, and classroom management techniques to enhance and improve student learning. An excellent example that illustrates the power of self-reflection and the interchange between teacher epistemological beliefs, prior life experiences, and their impact on self-efficacy and classroom practice is a year-long ethnographic study by Brand and Glasson (2004). Over the course of a year this study examined the ethnic and racial backgrounds of three diverse preservice science teachers as they crossed cultural boarders from their course preparation into the diverse setting of student teaching. Brand et al. (2004) employed a theoretical framework to guide their examination as well as proven methods to ensure the trustworthiness of the data and found three emergent themes that were supported across all three cases:

1. The early life experiences and racial and ethnic identity of pre-service teachers' influenced their beliefs on diversity.

2. Life experiences and racial and ethnic identity influenced preservice teachers' pedagogy and philosophy of teaching as they relate to the role of diversity in the classroom.
3. Experiences with diversity during the teacher preparation program challenged preservice teachers' preexisting beliefs.

Interestingly, while all three preservice teachers had formal instruction in inquiry-based methodology, each were observed using a more direct instructional method of lectures and note taking with their students. Through numerous open-ended interviews, Brand et al. (2004) uncovered unique reasons for these observations of direct instruction and conjectured that that they may be related to individuals unique prior life experiences, and personal beliefs concerning school and their unique ethnic and cultural identity. These findings inform the literature regarding the impact of beliefs as well as ethnic identity on classroom practice and show the importance of addressing teacher beliefs as part of preservice and inservice teacher preparation.

A final example of this intersection between formal general pedagogical knowledge and personal pedagogical knowledge as afforded within a specific context is the case by Smith (1999). This study which demonstrates the power of reflecting on one's own practice, as Smith chronicles her growth over time within her own the elementary classroom. These two examples also reflect the overlap and blurred distinction referenced earlier between pedagogy, subject matter knowledge and pedagogical content knowledge. As Shulman states in his original exposition:

> In every field of practice there are ideas that have never been confirmed by research and would, in principle, be difficult to demonstrate. Nevertheless, these maxims represent the

> accumulated wisdom of practice, and in many cases are as important a source of guidance for practice as the theory or empirical principles (1986, p. 11).

With a review of general pedagogy and its overtures towards a current constructivist paradigm now discussed, a more detailed examination of the components of pedagogical content knowledge with an illumination at the elementary education will follow.

Pedagogical Content Knowledge

Pedagogical content knowledge is knowledge unique to the field of education as it goes beyond knowledge of subject matter expertise to also include knowledge of how to teach the subject (Shulman, 1986). As Shulman posited in 1987, and has been demonstrated in numerous aggregated reviews in the novice-expert and education production literature (Bransford, et al., 2000; Clermont & Borko, 1994; Economic Policy Institute, 2003; Haycock, 1998; National Center for Research on Teacher Education, 1990), deep and flexible understanding of subject matter knowledge is a necessary condition for excellence in teaching, including the elementary level (Feiman-Nemser & Parker, 1990; Luera, 2005), but content knowledge in and of itself is not sufficient (Ball, 1990; Feiman-Nemser & Parker, 1990; Grossman, Wilson, & Shulman, 1989; Ma, 1999; Shulman, 1987). Pedagogical content knowledge as defined in the reviews of literature discuss the ability for educators to transform and apply deep content knowledge through appropriate and varied instructional strategies, materials, analogies, explanations, examples, and representations, coupled with an intellectual knowledge of the how students learn given their cultural predilections and dialectics (Abell, 2007; Gess-Newsome & Lederman, 1999; Ma, 1999).

For the purposes of this discussion Figure 2 depicts the model cited in Abell (2007) and will be used to guide the discussion of pedagogical content knowledge (PCK). This model incorporates additional components from other researchers, as well as an expansion by Shulman’s (1986) original work to incorporate the following components: (a) knowledge of science content, (b) knowledge of general pedagogy, (c) knowledge of curriculum, (d) knowledge of pedagogical content, (e) knowledge of learners and their characteristics, (f) knowledge of educational contexts, (g) knowledge of orientations toward teaching science, (h) knowledge of assessment, and (i) knowledge of science instructional strategies (Grossman, 1990; Magnusson, et al., 1999; Shulman, 1987). Expanding the knowledge base and PCK conceptual model to so many categories gave rise to challenges concerning the precision and predictive nature of the model’s ability to measure and discriminate between each PCK construct as aligned with the research data (Gess-Newsome, 1999a). Abell’s (2007) and Gess-Newsome and Lederman’s (1999a) reviews of the literature demonstrate that while PCK is a thriving and worthwhile conceptual model for research, with the exception of the PCK construct of teachers’ understanding of content knowledge, the findings across the other PCK constructs on a whole, are still open for study, inconclusive, sparse, or largely incoherent (e.g., use varied definitions, lack of redundancy in conceptual models, theories, and common citations). In Abell’s (2007) critique she confirms the significant empirical and theoretical advancements to the teacher knowledge based ignited by Shulman over 30 years ago, but given her comprehensive review of the literature, she challenges the research community for more coherence moving forward. A brief review of the components of PCK as related to content knowledge and their impact on elementary education will complete this section, excluding general pedagogical knowledge (previously discussed) as well as the knowledge of context as it is beyond the scope of this question.

Science Subject Matter Knowledge and its Relation to Teaching

A large body of early work related to the process-product literature, also looked at the presage-product relationships, and attempted to use overly simplistic variables such as number of courses, GPA, and fact-based subject matter tests to determine if a linear relationship existed between teachers' subject matter knowledge and student achievement. Research using this approach found only weak effects between teacher subject matter knowledge and student achievement (Abell, 2007; Grossman, et al., 1989). More recent and sophisticated analysis, looking at large panel-data, such as standardized state and national student assessment measures disaggregated to the teacher and student classroom level appear to find a positive correlation between teachers' content knowledge and student achievement, albeit the attribution is difficult to measure via proxy measures that do not account for all unobserved or omitted variables, even when matched comparison and multi-year value added approaches are part of the equation (Darling-Hammond & Youngs, 2002; Economic Policy Institute, 2003; Hanushek & Rivkin, 2007; Wilson, et al., 2002). Effects that are significant are more pronounced at the middle and high school levels (grades 6 and above), and in more challenging subjects such as math and science, and within science, the effects vary by discipline being taught (e.g., strong correlation between student achievement and physical science undergraduate preparation) (Darling-Hammond & Youngs, 2002; Whitehurst, 2002; Wilson, et al., 2002). In spite of the statistical measurement challenges, as Shulman (1986) originally posited, teachers need to have an understanding of the subjects matter they teach, which as elaborated by Grossman (1989), falls into three categories: (a) content knowledge (e.g., understanding of concepts, facts, and principles), (b) substantive knowledge (e.g., structure and conceptual framework how concepts and topics are organized), and (c) syntactic (e.g., canonical rules and processes by which knowledge in the discipline is formed). If elementary teachers charged with teaching science do not have understanding in these areas and their conception and beliefs concerning the nature of science is poor, research has shown significant and potentially negative impacts to their teaching in the following ways: (a) avoidance of teaching science altogether; (b) limiting time, structure, discourse and topics selected for learning; (c) utilization of instructional strategies and questions that may limit and fail to formatively assess and build upon students ideas to facilitate conceptual understanding; (d) failure to inculcate an understanding about the dynamic nature of science; and (e) facilitation of erroneous content knowledge and misconceptions in the students they are charged to teach (Abell, 2007; Abell & Smith, 1994; Appleton, 2007; Butts, Hofman, & Anderson, 1993; W. Carlsen, 1997; W. S. Carlsen, 1992; Garbett, 2003; Griffith, 2008; Grossman, et al., 1989; Harlen, 1997; Hashweh, 1996; Heywood, 2007; Howitt, 2007; Kang, 2007; C. A. Lee & Houseal, 2003; O. Lee, 1995; National Center for Research on Teacher Education, 1990; Parker, 2004; Schmidt & Buchman, 1983; Wilson, et al., 2002). It would seem from the literature above that at least to some degree, a lack of science content knowledge for teachers, when not part of a coherent conceptual framework, may limit their ability to effectively plan and deliver instruction, which in turn, may facilitate inert knowledge acquisition in their students as they wrestle with discrete sets of isolated facts and fail to gain an appreciation for the nature of science and inquiry that facilitates understanding of the concepts in question (Bransford, et al., 2000; Clermont & Borko, 1994; Desimone, Smith, & Ueno, 2006; Fishman, Marx, Best, & Tal, 2003; Garbett, 2003; Hanuscin & Lee, 2008; Heywood, 2007; Luera, 2005; Mundry, 2005; National Center for Research on Teacher Education, 1990; Weinburgh, et al., 2008). In a quantitative study examining 234 prospective elementary teachers Luera (2005) found a significant positive correlation between preservice teachers inquiry-based science content knowledge as measured on an independent state student assessment and teachers' ability to create an inquiry-based lesson as part of an open-book midterm exam. In support of the assertion that subject content knowledge in an of itself is not sufficient for excellence in instruction, this study corroborated that position finding that preservice elementary teachers taking traditional lecture-based science content courses did not do well on constructing inquiry-based lessons compared to those students who had learned science content through the modeled inquiry-science content courses. Similarly, very few students created successful inquiry lessons that had limited science content knowledge (Luera, 2005). These findings have implications for student learning.

As constructivist theorists espouse, students come to formal learning with existing understandings as they make sense of the world around them on both a personal and social level (Piaget, 1978; Rogoff, 1990; Von Glasersfeld, 1989; Vygotsky, 1986). It seems prudent that teachers charged with facilitating science content and reasoning ability in our children, work towards the same base level of science literacy espoused in the national standards (American Association for the Advancement of Science, 1993; National Research Council, 1996). As advocated by Feiman-Nemser (2001) regarding the importance of content knowledge:

> A continuing task for teachers who want to connect students and subject matter in powerful ways is deepening and extending knowledge of subject mater as represented by the disciplines and understood by students. This is particularly important task for elementary teachers who teach a broad range of subjects…With a better grasp of what they are responsible for teaching, post-induction teachers [after the first 3 years of service] are in a good position to identify areas of content they want to strengthen (p. 1039).

This discussion omits the line of arguments (pro or con) surrounding traditional or alternative routes to teacher certification (Baines, 2006; Darling-Hammond, Barnett, & Thoreson, 2001; D. D. Goldhaber & Dominic, 2000; Kennedy, 2008), with one caveat. It may make sense to consider professional development to address both existing content knowledge and pedagogical content knowledge practitioners bring with them as they embark into the teaching profession (Fishman, et al., 2003; Hewson, 2007; Penuel, Fishman, Yamaguchi, & Gallagher, 2007; Wilson, et al., 2002), structuring a lifelong learning experience that allows them to grow in knowledge appropriate to their areas of interest and need in support of the students they teach. A more in-depth discussion of the conceptual change literature and its implications for classroom instruction will be discussed in the section on learning theory.

Orientation towards Teaching of Science

In Magnusson, Krajcik & Borko’s (1999) review and expansion of the PCK construct they describe orientations toward science teaching as “teachers’ knowledge and beliefs about the purposes and goals for teaching science at a particular grade level,” (p. 97), and claim these orientations guide teachers’ decisions about the type of instructional strategies, materials and assessment methods they employ in the classroom. Magnusson et al. (1999) go on to provide a list of various orientations (e.g., activity driven, discovery, didactic, inquiry, guided-inquiry) and instructional characteristics supported by them. Abell’s (2007) later reviews in this area cite informative research that looks to operationalize these categories and their explanatory power as related to observed classroom practice (Brand & Glasson, 2004; D. C. Smith & Neale, 1989). Research shows that teachers’ beliefs affect their classroom practice. Many studies before those of Brickhouse (1990), Wenner (1993), and Lee (2003) acknowledge the strong relationship between teachers’ beliefs and attitudes, and their impact on classroom practice, which have been discussed previously in the pedagogical section of this paper. While Abell (2007) states that "orientations toward teaching science" is a "messy construct" (p. 1126), and one that is so broad it lacks coherence, elementary science research by Kang (2007), looks beyond epistemological beliefs into ontological examinations of concept development that seek to discern the practice of teachers' incorporation of student learning into their planning and delivery of lessons.

Knowledge of Science Learners

This PCK construct deals with teachers' understanding of particular subject and concept instructional strategies that facilitate student learning in specific grade and content domains, taking into account knowledge of how students learn and as well as an awareness of particular topics that may be more challenging for student understanding (Abell, 2007; Bransford, et al., 2000; Hennessey, 1999; Magnusson, et al., 1999). In a study by Jones (1999) working with two separate cohorts of 17 and 18 inservice elementary teachers respectively they confirmed the value of using a conceptual change model to increase teachers' understanding of their own misconceptions, and that of their students in the topics of light, sound and electricity. Teachers changed their practice as a result of the graduate course, and were astounded at the level of errors students had in their conceptual understanding. Abell's (2007) review concludes that while the conceptual change research has evolved with more constructivist sentimentalities, "overall, it appears that teachers lack knowledge of student science conceptions, but that knowledge improves with teaching experience" (p. 1128). With a large body of literature documenting various subject and topic specific metaphors, representations, and analogies in specific content areas (Lederman, 2001), and others synthesizing the literature on discourse and interactive demonstration techniques (Bransford, et al., 2000; D. E. Brown, 1992; D. E. Brown & Clement, 1989), many are now espousing a move in elementary education toward a focus on student metacognition of the ontological aspects of concepts to foster a deeper conceptual understanding (Appleton, 2007; Beeth & Hewson, 1999; Bransford, et al., 2000). A further discussion of conceptual change will be situated in the section regarding learning theory below.

Knowledge of Science Curriculum, Instructional Strategies, and Assessment

For brevity's sake and given the prior discussion regarding the fuzziness of PCK constructs, a collapse of the three remaining PCK knowledge areas for this topic are combined given: (a) an awareness of elementary and novice teachers inclination at times to closely follow the textbook, which typically include activities with strategies for their implementation and their assessment, albeit for ill or for good (Briscoe & Peters, 1997; W. S. Carlsen, 1992; Grossman, et al., 1989; Hashweh, 1987; Horizons Research, 2002; C. A. Lee & Houseal, 2003; O. Lee, 1995); and (b) current curriculum development approaches for science education look at these topics from a unified alignment and concurrent design perspective (Farenga, Joyce, & Ness, 2002; Keeley, 2005).

While science curriculum usually defines the sequence, structure, and selection of topics and content areas teachers follow, "instruction is the conduit through which teachers provide or facilitates factual, conceptual, or procedural knowledge to their students" (Farenga, et al., 2002 p. 53). This involves both an interpretation of the curriculum as well as the selection of materials, instructional approaches and aligned assessments that will be employed to reach predetermined target learning objectives for students (Farenga, et al., 2002; Keeley, 2005). In Farenga, Joyce, and Ness's (2002) essay they portend the lackluster student learning outcomes and low conceptual student understanding that will occur if only partial alignment between any two of the three areas are addressed (i.e., curriculum, assessment and instruction). They content that a "Zone of Optimal Learning" exist between curriculum, instruction and assessment that provides educators with the opportunity to blend a rich repertoire of open-inquiry with that of direct instruction labeled “adaptive inquiry,” which permits optimal flexibility for diverse student needs (Farenga, et al., 2002, p. 59). Abell’s (2007) review includes several elementary and high school research studies in the United States that demonstrated the following: (a) teacher beliefs and values affect what, how, and if they choose to assess student knowledge (Duffee & Aikenhead, 1992; Morrison & Lederman, 2003); and (b) alternative and authentic assessments can encourage student conceptual change as well as change in teacher practice as integration between assessment and instruction overlap and positive results in student achievement are realized (Kamen, 1996). Promising strategies within formative and alternative areas of assessment at the elementary level may include: (a) journals, (b) student portfolios, (c) science notebooks, and (d) concept maps, which show promising support of deeper conceptual learning as students reflect on their own understanding, and support integration with writing and language arts requirements (Appleton, 2007).

In a more discrete classification of knowledge of curriculum, Magnusson et al. (1999) divided this construct into two discrete areas: (a) knowledge of national and state goals and objectives, and (b) knowledge of specific curricular programming. As reported by Abell (2007), there are few studies conducted in the United States in each of these two areas, and from a research perspective, we know little of teachers’ knowledge in both of these areas. Studies that have been completed concerning teachers’ knowledge of various curricula show teachers generally lack knowledge of alternatives. These findings may be compounded in part to No Child Left Behind legislation and annual yearly progress accountability testing ("No Child Left Behind Act," 2001), which as some posit, leave little time, capacity or permissibility to deviate from the prescribed curriculum (Elmore, 2004; Griffith, 2008).

Research concerning teachers' pedagogical knowledge of various instructional strategies related to both subject-specific and topic-specific content areas is what distinguishes it from the generic behaviorist process-product classroom management strategies (Magnusson, et al., 1999; Shulman, 1986). Various content-specific instructional strategies and teachers' knowledge of them are treated in the review regarding conceptual change literature later in this response. Culminating this section with a comparative example between the instructional lesson and unit planning of Chinese versus United States teachers may shed light on "how" one might go about the analysis and integration of curriculum, instruction and assessment.

In a comparative study looking at the differences between Chinese and American teachers, Ma (1999) found Chinese teachers had significant time to create packages of conceptual knowledge based on the needs and abilities of their students. Accomplished through a process called lesson study, teachers had a breadth and depth of flexible content knowledge that allowed them to create, revise, and assess the effectiveness their curriculum units. This was not performed by teachers working in isolation or ignoring effects on student outcomes. Ma (1999) reports Chinese teachers are permitted substantial time for serious deliberation to collectively review and discuss their analysis of curriculum, instructional strategies, and materials to support their development of lesson plans and assessments. Conversely, cites Ma (1999) and Stigler (1997), U.S. teachers have essentially no time within the school day for similar collegial lesson discourse, which may result in American teachers going many years without deepening their professional teaching knowledge. Since this research, there has been a similar movement in creating school-based professional learning communities to provide similar lesson study, but these communities need nurturing to be successful (Dooner, Mandzuk, & Clifton, 2008). A recent longitudinal study in the United States analyzing the impact of a large teacher professional development effort in math and science included analysis and classroom observations of teacher designed lessons and reported the following (Banilower, Heck, & Weiss, 2007):

> A national observation study of a representative sample of classes found that only 14% of science lessons were of high quality, providing students an opportunity to learn important science concepts (Banilower, Smith, Pasley, & Weiss, 2006). The problem was not so much the content of the lessons, which was generally accurate, important, and developmentally appropriate. Where lessons tended to fall short was in the quality of teacher questioning to monitor student understanding, and in the lack of ‘‘sense-making’’ to develop conceptual understanding. (2007, p. 376)

Thus, it would seem important that in understanding teachers’ knowledge of curriculum, instructional strategies, and assessment, researchers should examine of the linkages between each be part of the equation (Farenga, et al., 2002). A final synopsis of pedagogy as informed by the perspective of learning theory will complete this review.

Learning Theory Implications and Their Impact on Pedagogy

For this section a distinction will not be made between general pedagogical knowledge and pedagogical content knowledge as this is already addressed above and the cognitive theorists described below did not make those distinctions at the time their theories were in development. Regardless, an explicative look at these theories is fruitful and will demonstrate refinements in pedagogical approaches over time. Most recent pedagogical practices have been impacted by constructivist-based learning theories, which acknowledge students construct their own understanding based on prior knowledge and sense-making of the world around them and through social discourse and culture negotiate learning, which ultimately through apprenticeship scaffolding is internalized into their existing internal mental structures through accommodation and assimilation as new knowledge is created through self-regulation, reflection and conceptual organization (Akerson, Flick, & Lederman, 2000; D. P. Ausubel, 1963; David P. Ausubel, 1978; Bransford, et al., 2000; D. E. Brown & Clement, 1989; Driver, Guesne, & Tiberghien, 2000b; Driver, Squires, Rushworth, & Wood-Robinson, 2003; Lave & Wenger, 1991; Lawson, 1995; Piaget, 1978; Posner, et al., 1982; Randell, 2001; Vygotsky, 1978, 1986). See Cakir, M. (2008), Rogoff, B. (1990), and Scott, P. (2007) for reviews of the differences between the constructivist perspectives of cognitive psychologists Ausubel, Vygotsky, and Piaget. A brief review of each and how their theories related to pedagogical learning will follow.

Piaget, Ausubel, and Conceptual Change

Piaget focused on the individual learner and posited an internal construction of learning where ideas were either assimilated into existing schema or recreated through accommodation into new structures as students wrestle with their existing beliefs and knowledge to reach a state of equilibrium. From a pedagogical perspective Piaget's work undergirds the conceptual change literature which suggests teachers address students' prior knowledge through strategies that make student understanding visible through higher-order cognitive questioning strategies, such as predict-observe-explain demonstrations (Treagust, 2007), student initiated questions with reflective analysis and discourse (Beeth & Hewson, 1999; Bransford, et al., 2000; van Zee & Minstrell, 1997), and ongoing formative assessments (Bransford, et al., 2000; Tomanek, Talanquer, & Novodvorsky, 2008). Other pedagogical strategies from the literature on conceptual change recommend the following: (a) facilitate cognitive dissonance through discrepant events (Driver, Guesne, & Tiberghien, 2000a; Driver, et al., 2000b); (b) generate learner awareness with his or her existing conceptions (Driver, et al., 2003; Posner, et al., 1982); (c) present plausible, intelligible, and fruitful conceptions that build bridges from students' valid anchored understandings and existing beliefs (Beeth & Hewson, 1999; Bransford, et al., 2000; D. E. Brown & Clement, 1989; Posner, et al., 1982); and (d) incorporate various forms and levels of representations (virtual and physical), authentic analogies, and metaphors as students metacognitively reflect and create new understandings through discourse (Bransford, et al., 2000; Hennessey, 1999). Ausubel’s contribution to Piaget’s work stressed less discrete developmental stages in knowledge construction. Instead, he focused more on the domain and contextual influences that affect learning (Wandersee, Mintzes, & Novak, 1994), and generated the pedagogical practice of student concept mapping as a means to integrate and organize knowledge in a coherent manner (D. P. Ausubel, 1963; Cakir, 2008). Although, Ausubel (1978) was not without detractors. Early conceptual change research focused more on the internal conceptual learning processes seeking to supplant one concept for another, and posited the eight following assertions (Wandersee, et al., 1994, p. 195):

1. Learners come to formal science instruction with a diverse set of alternative conceptions concerning natural objects and events.
2. The alternative conceptions that learners bring to formal science instruction cut across age, ability, gender, and cultural boundaries.
3. Alternative conceptions are tenacious and resistant to extinction by conventional teaching strategies.
4. Alternative conceptions often parallel explanations of natural phenomena offered by previous generations of scientists and philosophers.
5. Alternative conceptions have their origins in a diverse set of personal experiences including direct observation and perception, peer culture and language, as well as in teachers' explanations and instructional materials.

6. Teachers often subscribe to the same alternative conceptions as their students.
7. Learners prior knowledge interacts with knowledge presented in formal instruction, resulting in a diverse set of unintended learning outcomes.
8. Instructional approaches that facilitate conceptual change can be effective classroom tools.

In light of recent constructivist literature, the focus on conceptual change research in science education (and elementary education) now shifts to a more gradual additive or cumulative view of concept development versus concept replacement, taking into account the social, affective, and contextual influences that guide the building of knowledge (Appleton, 2007; Scott, et al., 2007). From the individual perspective, the notion of teachers attempting to overturn students' misconceptions using counterevidence to supplant the misconception with correct concepts is now more aptly described as the notion of working within students' existing theoretical frameworks to help them correctly categorize and incorporate concepts into their ontological frame of reference, which research on novice-experts show facilitates deeper understanding and the ability to apply the knowledge in practice (Bransford, et al., 2000; Chi, Slotta, & de Leeuw, 1994; diSessa & Sherin, 1998; Kang, 2007; Scott, et al., 2007). From a synthesis of the current literature on the individual nature of conceptual change Scott (2007, p. 38) coalesces the eight assertions from Wandersee (1994) into three:

1. Individuals' beliefs about the natural world are constructed, rather than received.
2. There are strong commonalities in how individuals appear to think about the natural world.
3. A person's existing ideas about a given subject greatly influence his/her subsequent learning about the subject.

In closing, the discussion on conceptual change when viewed from a socially constructed knowledge perspective, envisions the teacher enculturating learners to the language and symbols of science through collaborative classroom discourse and tools, facilitating knowledge by building on students existing ontological and epistemological frameworks and addressing the challenges between everyday world and that of the science community (Beeth & Hewson, 1999; Driver, Asoko, Leach, Mortimer, & Scott, 1994; Scott, et al., 2007)

Vygotsky, Social Constructivism and Inquiry-based Learning

Vygotsky's constructivist underpinnings are different from those of Piaget and Ausubel in that he focused not on the individual or internal, but on the external and social construction of knowledge, whereby younger adults socially construct meaning through enculturation as entrenched in the social milieu and tools of that culture (e.g., language), which in large part is facilitated through problem solving with assistance by those more knowledgeable via zones of proximal development (Rogoff, 1990; Vygotsky, 1978). Experts scaffold activities in social settings just beyond learners' abilities as solutions are generated. Pedagogical implications for the classroom reflect Vygotsky's theories through establishing authentic classroom contexts for student learning that incorporate students' cultural backgrounds, provide apprenticeship models of support, and structure small group and collaborative activities that incorporate inquiry-based strategies, such as the learning cycle to facilitate learning science (Appleton, 2007; Glasson & Lalik, 1993; Hanuscin & Lee, 2008; Lawson, 1995; National Research Council, 1996, 2000; Roth & Bowen, 1995; K. Tobin & Fraser, 1990; K. Tobin, et al., 1994; Treagust, 2007).

These constructivist theories shift the instructional model away from a transmission behaviorist "process-product" delivery model, where the teacher is the primary deliverer of information (Gunel, 2008; Roth & Bowen, 1995; K. Tobin, et al., 1994), to that of a student-centered approach, where the teacher is more of a mentor facilitating guided participation (Appleton, 2007; Driver, et al., 1994; Morine-Dershimer & Kent, 1999; Rogoff, 1990; Rogoff, Turkanis, & Barlett, 2001; Scott, et al., 2007; Vygotsky, 1986). In this view the student is situated within a classroom community of practice where they can negotiate meaning through discourse, engaging in active inquiries as the teacher scaffolds learning (J. S. Brown, Collins, & Duguid, 1989; Driver, et al., 1994; Lave & Wenger, 1991; Scott, et al., 2007). In this environment teachers design and facilitate authentic learning experiences that support collaborative student learning that enable students to: (a) generate their own questions about natural phenomena and the world around them, (b) reflect and discuss their existing conceptions and understanding, and (c) emulate how knowledge is derived in science (e.g., being curious and inquisitive, making observations, generating questions, researching what is known already, forming hypotheses and predictions, designing investigations, collecting and analyzing data, sharing, discussing and negotiating results, and understanding the nature of how scientists construct knowledge) (Akerson, Abd-El-Khalick, & Lederman, 2000; Barr, 1994; Driver, et al., 1994; Driver, et al., 2003; Kang, 2007; Mestre & Cocking, 2002; National Research Council, 1996, 2000; Roth & Bowen, 1995; Scott, et al., 2007; K. Tobin, et al., 1994). These epistemological and ontological processes concerning the nature of science (Driver, et al., 1994) are referred to as *inquiry* in the *National Science Education Standards* (1996), which serves as both as a content and process standard for learning, thus showing its import of facilitating scientific literacy for all students. Scientific literacy as described by the National Research Council states:

> Scientific literacy means that a person can ask, find, or determine answers to questions derived from curiosity about everyday experiences. It means that a person has the ability

> to describe, explain, and predict natural phenomena. Science literacy entails the ability to read with understanding articles about science in the popular press and to engage in social conversation about the validity of conclusions. Scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed. A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it. Scientific literacy also implies the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately (National Research Council, 1996, p. 22).

Many in the elementary science education literature espouse the use of a constructivist learning cycle model as a proven inquiry-based instructional process that has been shown to enhance student achievement, attitudes toward science, retention of concepts, and increased higher-order cognitive reasoning skills (Gerber, Cavallo, & Marek, 2001; Glasson & Lalik, 1993; Hanuscin & Lee, 2008; Lawson, 1995; Marek, Gerber, & Cavallo, 1999). Thus it is goal of teachers at each grade level to facilitate cognitively appropriate, relevant, authentic, and challenging activities that afford students the opportunity to developing enduring content knowledge and the critical habits of mind acquired in part through inquiry-based learning experiences (American Association for the Advancement of Science, 1993). With a pedagogical review from the perspective of learning theory and educational psychology addressed, a brief conclusion on the importance of pedagogical content knowledge will conclude this response.

The Impact of Instructional Practice on Student Learning

Perhaps a review from the perspective of what has and is occurring in our nation's classrooms may provide a culminating focal lens on the importance and impact of teacher pedagogy and pedagogical content knowledge. Richard Elmore provides an insightful empirical review of our country's classrooms, and through a historical retrospective argues that what occurs today within the "core" of the classroom is not substantively different then what has been occurring for decades, even though from an external point of view, there appears to have been significant change in the structure of education when one looks at what has occurred since John Dewey's progressive movement of the early 20th century (Elmore, 2004).

Science education case studies (Simmons, et al., 1999; D.C. Smith, 1999; K. Tobin & Fraser, 1990), literature concerning the nature of science and pedagogy (Akerson & Hanuscin, 2007; Akerson, Morrison, & McDuffie, 2006; Lederman, 1992, 2001), and research concerning belief structures of teachers (Brand & Glasson, 2004; Grossman, et al., 1989; Nespore, 1987; Pajares, 1992; K. Tobin, et al., 1994; Wenner, 1993), lend keen insight to understanding the factors that guide teacher practice, which often times show teachers reverting back to a behaviorist model that emulates how they were taught, which is not supportive of the reform efforts espousing inquiry-based instruction (Akerson, et al., 2006; Bryan & Abell, 1999; Glasson & Lalik, 1993; Hanuscin & Lee, 2008; M. G. Jones & Carter, 2007; C. A. Lee & Houseal, 2003; National Center for Research on Teacher Education, 1990; Simmons, et al., 1999; K. Tobin, et al., 1994). When preservice preparation or inservice professional development is of an insufficient structure or duration to avoid this tendency, the research posits that it typically results in a more didactic teacher-centered transmission model of instruction, which may at times involve: (a) heavy use of lecture and whole class triadic dialogue for control and authority (W. Carlsen, 1997; W. S. Carlsen, 1992; Glasson & Lalik, 1993; Hanuscin & Lee, 2008; Horizons Research, 2006; Kelly, 2007; Roth, 1996), and (b) worksheet and textbook questions that rely more on memorization of isolated facts (C. A. Lee & Houseal, 2003; O. Lee, 1995) outside of a conceptual framework that facilitates deeper understanding (Akerson & Hanuscin, 2007; Borko & Putnam, 1996; Driver, et al., 1994; Horizons Research, 2006; O. Lee, 1995; National Center for Research on Teacher Education, 1990; K. Tobin & Gallagher, 1987; K. Tobin, et al., 1994). Understanding the challenges and concerns elementary teachers face as they attempt to develop, implement, or change their teaching practice is not difficult to conceive. The literature confirms the importance of addressing existing teachers' epistemological and ontological beliefs about pedagogy, their views concerning the nature of science, and their self-efficacy and ability with respect to science subject matter knowledge from preservice training and throughout their entire professional careers (Abell, 2007; Akerson & Hanuscin, 2007; Brand & Glasson, 2004; Feiman-Nemser, 2001; Gess-Newsome, 1999b; Glasson & Lalik, 1993; Grossman, et al., 1989; Horizons Research, 2002; M. G. Jones & Carter, 2007; Kang, 2007; Keys & Bryan, 2001; Pajares, 1992; Rigden, 1983; Simpson, Koballa, Oliver, & Crawley, 1994; K. Tobin & Fraser, 1990; K. Tobin & Gallagher, 1987; K. Tobin & Garnett, 1988; Wenner, 1993).

Surprisingly, the instructional practice in science classrooms today and in education classrooms in general reveals some interesting findings. Research studies have shown that the classroom environment has changed very little over the last 30 to 40 years, in spite of ongoing reform efforts since the 1950's, and as such, various researchers believe that indeed, unless we focus on the "core" of instruction, which occurs between the teacher, student, and content, we will continue to see little change in student learning outcomes (Cuban, 1990; Elmore, 2004; C. A. Lee & Houseal, 2003; National Center for Research on Teacher Education, 1990; K. Tobin, et al., 1994; Tyack & Tobin, 1994; U.S. Department of Education, 2000). For example, Elmore discusses the large NSF science and mathematics curriculum reform movement of the 1950's and 1960's that trained hundreds of thousands of teachers through summer institutes and distributed tens of thousands of curriculum units such as that from the Physical Sciences Study Committee (PSSC), or the Biological Sciences Curriculum Study (BSCS), only to find little or negligible impact on core function or attitudes of students in U.S. schools (Gruber, 1963; Simpson, et al., 1994; Stake & Easely, 1978). Elmore defines the core of educational practice as: (a) "how teachers understand the nature of knowledge and the student's role in learning," (b) " how these ideas about knowledge and learning are manifested in teaching and class work," (c) the "structural arrangements of schools," (d) "student grouping practices," (e) "teachers' responsibilities for groups of students and relations among teachers in their work with students," and (f) "processes for assessing student learning and communicating it to students, teachers, parents, administrators" (Elmore, 2004, p. 8). Ultimately, a rich repertoire of content specific pedagogical skills, deep and flexible subject matter knowledge and positive self-efficacy about ones abilities, as well as an understanding of nature of science (Akerson, Abd-El-Khalick, et al., 2000; Barr, 1994; Bransford, et al., 2000; Gess-Newsome, 1999b; Grossman, et al., 1989; Keys & Bryan, 2001; Morine-Dershimer & Kent, 1999; Morrison, Raab, & Ingram, 2008; Pratt, 2002; Shulman, 1986, 1987; Simpson, et al., 1994), may make substantive change in teacher classroom instruction, which in turn may significantly improve student learning (Bransford, et al., 2000; Magnusson, Borko, Krajcik, & Layman, 1992; Magnusson, et al., 1999 ; D.C. Smith, 1999), as espoused in the nationals science standards (American Association for the Advancement of Science, 1993; National Research Council, 1996, 2000).

It is axiomatic to state the importance of improving elementary teachers' knowledge of both the subject matter and the salient components of pedagogical content knowledge (e.g., understanding of how students learn, use of representations, and appropriate instructional strategies, such as the learning cycle) to facilitate discursive inquiry-based learning that draws on the beliefs, prior knowledge and culture of students (Brand & Glasson, 2004; Glasson & Lalik, 1993; Parker, 2004). By understanding and facilitating ways for students to increase their understanding in a deeper more coherent manner (Scott, et al., 2007), we stand the greatest chance to break through the stagnant growth in student learning that has been reflected for decades through various reform efforts mentioned earlier. As Howes (2002) so eloquently states:

> Understanding scientific concepts and understanding scientific practices as socially constructed do not take precedence one over the other, nor do they follow each other in a linear sequence. They are instead thoroughly intertwined and challenge teachers to develop not only science content knowledge but knowledge of the role of science in our society, and knowledge of the children and communities whom we serve (2002, p. 864).

This will not be an effort that teachers can do by themselves, but with a concerted, school-wide effort focused on changing the “core” interaction between the teacher, student and instructional content, we can move closer to allowing all children the opportunity to reach their highest aspirations and move towards the goal of scientific literacy for all Americans (Elmore, 2004).

Figure Caption

Figure 1. Facets of Pedagogical Knowledge. Depicted in 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, p 23). Boston, MA: Kluwer Academic Publishers.

Figure 2. A Model of Science Teacher Knowledge. Depicted in Abell, S.K. (2007). Research on science teacher knowledge. In Abell, S.K. & Lederman, N.G. (Eds.), Handbook of research on science education (p. 1105). Mahwah, NJ: Lawrence Erlbaum Associates.

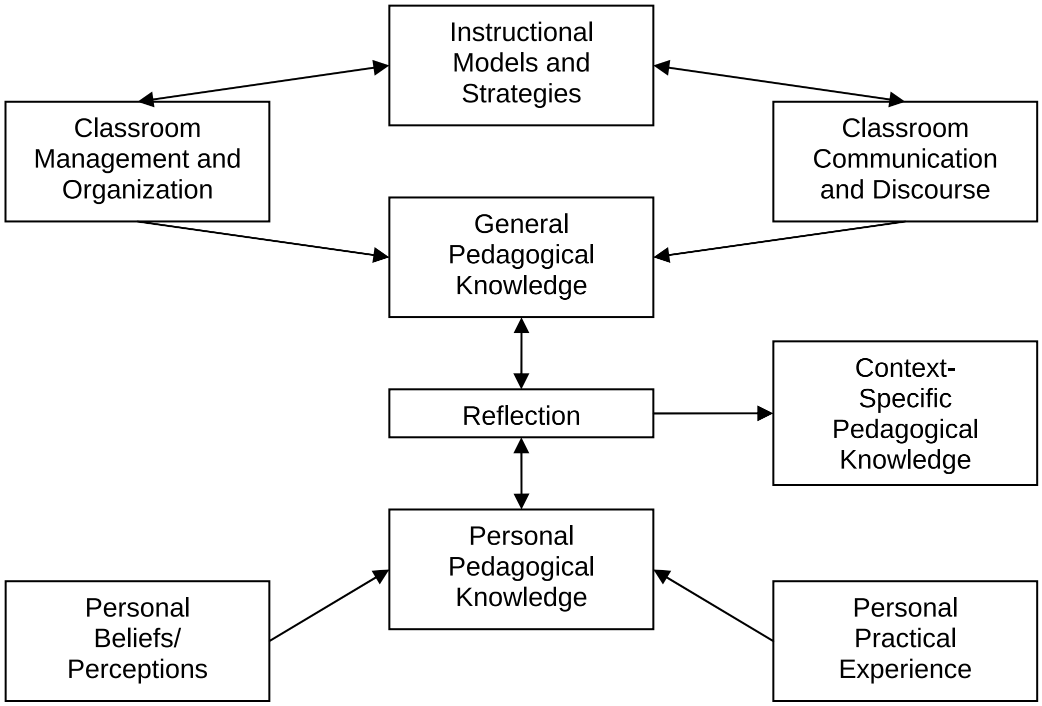

Figure 1. Facets of Pedagogical Knowledge

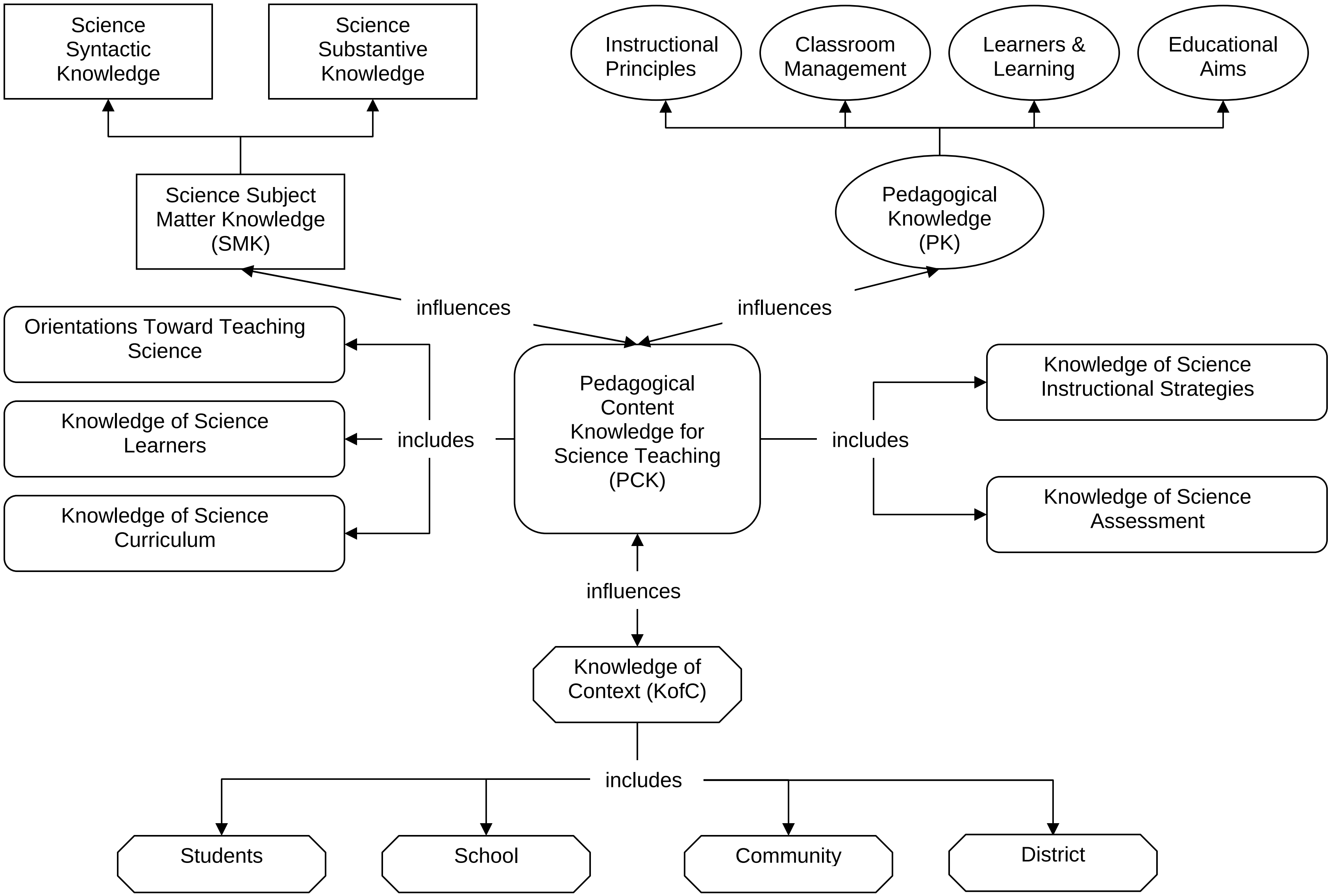

Figure 2: A Model of Science Teacher Knowledge

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