Chapter 33
Research on Science Teacher Beliefs

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In the mid-1980s, the confluence of the publication of the three landmark documents [*A Nation Prepared: Teachers for the 21st Century* (Carnegie Commission Task Force 1986), *Handbook of Research on Teaching*, (3rd ed., Wittrock 1986), and *Tomorrow's Teachers* (The Holmes Group 1986)], advances in cognitive psychology (particularly as it pertained to teaching), and the increasing popularity of qualitative approaches to educational research propelled research in the domain of teacher thinking in a new direction. Researchers saw promise in examining and understanding the mental constructs and thought processes underlying teacher behavior as a way to yield meaningful changes to practice. A marked shift occurred in how teacher education research was framed – from a *training* perspective that identified and examined the most effective instructional approaches for preparing teachers to perform specific behaviors to a *learning* perspective that sought to understand teachers' knowledge development. Teacher educators began to examine teachers' knowledge and educational beliefs, how knowledge and beliefs change over time, and how teachers' translate knowledge and beliefs in to classroom practices. Research began to focus on the integral relationship between beliefs and actions in order to develop a complete and useful understanding of teachers' thought processes (Cochran-Smith and Fries 2005). Concomitantly, new reform initiatives were emerging in science education, particularly in the USA, calling for the implementation of widespread, diverse, and substantial innovations in science classrooms. Hence, the need to examine teachers' beliefs in relation to their decision making about classroom practices became paramount.

More than two decades later, the field of science education has amassed a literature base on teacher beliefs that establishes that teachers are creative, intelligent decision makers who hold complex systems of beliefs that influence how they view students,

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themselves, and science. Science education research has moved from simply describing beliefs and practices toward developing explanations for how beliefs influence practices and vice versa (i.e., why teachers do what they do in the science classroom). This review of international studies on science teacher beliefs attempts to depict the most salient themes that have emerged from more than 25 years of science education research on teacher beliefs. It is not an attempt to report an exhaustive review of literature, but instead provide a survey of informative studies in the field from an international perspective. In addition, this review primarily focuses on research that examines teachers' epistemological and pedagogical beliefs, and does not include large subsets of research literature related to science teacher beliefs such as teacher knowledge, attitudes, and self-efficacy beliefs.

Defining Beliefs

As research on teacher beliefs has gained attention in the science education literature over the past two decades, it is well noted that there is not one consensus definition of beliefs consistently used in the literature. Pajares (1992) referred to the problem of defining beliefs as "at best a game of player's choice" (p. 309), noting that one may find numerous aliases for the construct of beliefs in educational literature. Nonetheless, several works have emerged as being influential in the conceptualization of beliefs as a guiding construct for contemporary teacher thinking research. Among the most prominent scholarship cited in science education research are the works of Milton Rokeach (1968) and Thomas Green (1971), Jan Nespor's Teacher Belief Study (1987), and Frank Pajares's review of teacher belief research (1992). Reviews and analyses of this literature contribute to a consensus that beliefs are part of a group of psychological constructs that describe the structure and content of human thought that is presumed to drive a person's actions. In addition, keeping with the traditional philosophical literature, the term belief implies a construct different from knowledge. Green (1971) stated that while knowledge and beliefs are remarkably similar, the difference between them "seems to lie in the truth condition" (p. 69). Similarly, according to Pajares (1992) the most commonly, albeit "artificially," used distinction between beliefs and knowledge is: "Belief is based on evaluation and judgment; knowledge is based on objective fact" (p. 313). In other words, knowledge carries a kind of epistemological assurance that beliefs do not. Furthermore, from this research a number of fundamental assumptions that characterize beliefs can be derived:

- Beliefs do not exist in complete independence of one another, but are structured into an "internal architecture" of systems that are psychologically, but not necessarily logically organized.
- Not all beliefs are of equal importance to the individual. They are prioritized according to their relationship to other beliefs or other cognitive and affective structures.

- Beliefs are held along a continuum of centrality – some are more central, core, or primary, than others. It follows that the more central a belief is, the more resistant to change that belief will be.
- When a belief is changed, the centrality of that belief has repercussions for the entire belief system.
- Beliefs are far more influential than knowledge in discerning how individuals frame and organize tasks and problems and are stronger predictors of behavior.

Finally, there is a complex relationship between beliefs and actions. Rokeach (1968) argued that what a person espouses as a belief may or may not represent accurately what the person truly believes. He suggested that beliefs cannot be directly observed, but rather beliefs "must be inferred as best one can, with whatever psychological devices available, from all the things the believer says or does" (p. 2). In this vein, what a teacher does in the classroom is representative of his or her beliefs and should not be taken as a separate entity from a teacher's belief system.

Regardless of the limitations or concerns about the definition of beliefs, we do know that beliefs are personal constructs that may provide an understanding of a teacher's practice, and the nature of that relationship, while not simple, is becoming better understood and described in science education research.

Methods for Ascertaining Beliefs in Science Education Research

Science educators have employed numerous methods for ascertaining and reporting on teacher beliefs. When investigating teacher beliefs, most researchers make a distinction between espoused beliefs and beliefs as they are inferred from practices.

Espoused Beliefs

Espoused beliefs are self-reported claims about the way things are or should be. In other words, espoused beliefs are what we say, but not necessarily what we do. Interviews, questionnaires and Likert-style surveys are commonly employed to determine teachers' espoused beliefs. Many researchers design their own context-based instruments such as semi-structured or structured interview protocols and theoretically grounded surveys based on characteristics of a specific national curriculum or intervention programs. Within the last decade, several standardized protocols and validated surveys have been disseminated through the science education literature, including *Attitudes and Beliefs About the Nature of and the Teaching of Mathematics and Science* (McGinnis et al. 2002), *Context Beliefs About Teaching Science* (Lumpe et al. 2000), *Inventory of Scientific and Pedagogical Beliefs* (Porlán 1989 as cited in Porlán and Martín del Pozo 2004), and *Teachers' Pedagogical Philosophy Interview* (Richardson and Simmons 1994 as cited in Simmons et al. 1999).

While quantitative survey instruments and questionnaires such as those described above assist in the comparison of teachers' espoused beliefs (particularly over large

populations and between studies), they often veil the details of teaching–learning interactions and the contextual nature of teachers' beliefs. To uncover the idiosyncrasies and contextual nature of teacher beliefs, several studies have employed methods that require teachers to respond to various prompts such as classroom scenarios. One such methodology is the repertory grid technique based on Gregory Kelly's (1963) personal construct theory. Examples of studies that used this technique include the works of John Olson (1981) and Hugh Munby (1984).

Additionally, science educators have used critical incidents, metaphors, and case-based approaches to educe a more detailed portrait of teachers' beliefs. For example, Nam Hwa Kang and Carolyn Wallace (2004) used critical incidents as a tool for identifying teachers' epistemological beliefs. Ken Tobin and colleagues have used metaphors as a vehicle to elicit teachers' beliefs about teaching and learning (e.g., Tobin and LaMaster 1995). Sandra Abell et al. (1998) ascertained teachers' pedagogical beliefs using video cases and a series of reflective prompts in which teachers responded to video case scenarios of other teachers' instruction.

Beliefs Inferred from Teachers' Actions

Espoused beliefs may or may not be consistent with the actions carried out by an individual. Hence, many studies in science education examine teachers' beliefs-in-action: the beliefs that implicitly guide and are inferred from teachers' actions. Methods used to examine teachers' beliefs as inferred by their actions include prolonged field observations documented in field notes, observational protocols, and videotaping. For example, over the past several years, science educators have begun to use digital editing tools to help teachers build "cases" of their own teaching not only for research purposes but also for facilitating teachers' reflection upon and refinement of their beliefs and practices**.** The *Video Analysis Tool* is a web-based resource that has been used in several teacher belief studies while also serving as a robust and flexible pedagogical resource for teacher education courses (Bryan and Recesso 2006). Randy Yerrick and colleagues (2005) have used *iMovie* for similar purposes. Within the last decade a few standardized rubrics for gathering observational data for teacher belief research have been disseminated through the science education literature including the *Secondary Teacher Analysis Matrix* (Gallagher and Parker 1995 as cited in Simmons et al. 1999) and *Science in Schools Component Mapping* (Tytler et al. 2004).

Salient Themes in Science Education Research on Teacher Beliefs

Many significant contributions to understanding teacher beliefs have been made by scholars in the field of science education. This research presents a portrait of both prospective and practicing teachers who hold deeply entrenched beliefs about teaching and learning, their students, and subject matter. Many studies profile teachers'

beliefs in a "snapshot" of time, portraying espoused beliefs as congruous or incongruous with teachers' actions in the classroom. This research is unquestionably important, but should not be construed as implying that beliefs cannot change. Indeed, beliefs are strongly held and relatively static in nature (Rokeach 1968); however, they can be provoked to change. Studies that examine change in beliefs over time often occur within the context of a teacher education program or an intervention aimed at facilitating teachers' refinement of beliefs and actions to be congruous with reform initiatives. Finally, there is a small but emerging set of studies that examine the complexity of teacher beliefs and belief systems.

Congruity Thesis

A number of studies have concluded that s*cience teachers possess beliefs about teaching and learning that influence their classroom practices.* This subset of beliefs literature demonstrates a congruity thesis – that is, the findings depict congruity between a teacher's espoused beliefs and classroom practices. The congruity thesis especially seems to hold true for teachers who espouse empiricist/positivist views about science and behaviorist/transmissionist beliefs about learning.

In her seminal case study, Nancy Brickhouse (1990) examined the nature of science beliefs and teaching practices of one US beginning middle school teacher and two US veteran high school science teachers. The two veteran teachers' understandings of the nature of science and how students learn science formed a consistent set of beliefs for guiding their classroom practice. However, many obstacles prevented the beginning teacher from implementing instructional strategies that were congruous with his beliefs. Brickhouse concluded that teachers' beliefs about the nature of scientific theories, the nature of scientific processes, and the progression and change of scientific knowledge influenced not only their explicit lessons but also an implicit curriculum about the nature of science.

Teacher beliefs about themselves and students as knowers of science have also been shown to influence teachers' classroom practices. Bernard Laplante (1997) reported on the profound influence that the epistemological beliefs of two Canadian elementary teachers had on their choice of teaching strategies. The teachers viewed themselves as consumers of science knowledge (as opposed to inquirers of science) and science as a body of knowledge (as opposed to a process of inquiry). Their teaching reflected these beliefs – the use of teacher-centered strategies in which students engaged in closely controlled activities and were cast as receivers of decontextualized knowledge transmitted by the teacher.

A system of reinforcing beliefs that included traditional positivist-empiricist beliefs and a belief about control of the classroom were found to be particularly influential in driving the practices of a 14-year veteran Mexican high school biology teacher, Maria. In their in-depth case study, Janet Verjovsky and Guillermina Waldegg (2005) concluded that Maria possessed a strongly held system of beliefs that was markedly coherent with her practices. This belief system served as a

powerful filter through which Maria unconsciously interpreted new models of teaching and learning and resulted in difficulties in establishing a collaborative learning environment.

The congruity thesis has been demonstrated among prospective teachers as well. In a study of 74 secondary student teachers at the University of British Columbia, Jose Aguirre and colleagues (1990) examined student teachers' beliefs about the nature of science, science teaching, and science learning. Nearly 50% of the student teachers held a belief about teaching as knowledge transfer from sources of authority (such as the teacher's mind and textbooks) to the students "empty" minds. Correspondingly, nearly 50% of student teachers viewed learning as the intake of knowledge. They concluded that holding a positivist-empiricist view of science may be a significant disposition leading student teachers to adopt a more transmissive approach to teaching.

While the majority of studies that demonstrate congruity between beliefs and practices focus on empiricist/positivist views about science and behaviorist/transmissionist beliefs about learning, notably there are a few studies that portray teachers whose classroom practices are congruous with their espoused constructivist epistemological beliefs. For example, in a study that examined teachers' beliefs about the nature of science, Larry Bencze et al. (2006) found that Canadian teachers' espoused beliefs about science, whether positivist or constructivist, broadly corresponded to their tendencies to control student knowledge building or promote student-centered, open-ended scientific inquiries. Specifically, the pedagogical repertoire of teachers who believed that science involves highly systematic methods that lead to conclusions matching reality tended to include teaching practices such as lectures, multimedia presentations, whole-class guided questioning, text reading, and completion of worksheets. On the other hand, when teachers held beliefs that were congruous with a social constructivist view about science, they utilized practices that enabled students to engage in student-directed, open-ended scientific inquiry projects in which students designed their own methods to develop and evaluate knowledge claims.

Similarly, Maher Hashweh (1996) found in a study of Palestinian teachers who held contrasting epistemological beliefs that constructivist teachers used multiple strategies to facilitate students' learning of new conceptions including the elicitation of alternative conceptions and facilitating cognitive restructuring. They had a richer repertoire of teaching strategies. On the other hand, empiricist teachers used presentation of information, explain-and-convince methods, and repetition strategies more often. Hashweh concluded that the effects of teachers' epistemological beliefs are strong and stable across teachers' field of expertise in science and the education level at which they teach.

Influence of Teacher Beliefs on Science Curriculum Implementation

The studies described so far have examined the congruity of teachers' beliefs vis-à-vis their classroom practices so as to establish the influence that beliefs have on teachers' practice. Another set of studies that have demonstrated the influence of

science teachers' beliefs on their practices are those conducted in the context of implementation of curriculum innovations and science education reform initiatives. In these studies, the teachers' beliefs and practices, while congruous, typically were in direct contrast with important reform-oriented elements and goals of the innovations. The predominant findings in these studies portray teachers who translated reform-oriented initiatives to "fit" with teaching practices that were strongly supported by their espoused beliefs. These studies document the critical relationship between teachers' beliefs and instructional decisions and demonstrate that *teachers' beliefs mediate the curriculum implementation process.*

For example, one of the earliest studies examining science teachers' beliefs in the context of reform-based curriculum implementation was conducted by John Olson (1981). In this study, Olson examined the beliefs and practices of eight Canadian teachers who participated in the implementation of the English Schools Council Integrated Science Project (SCISP). Utilizing the repertory grid technique, Olson elicited "a picture of [the teachers'] thinking about classroom activity, and particularly about relationships with the students" (p. 262). Olson found that when the teachers attempted to implement the innovative curriculum, they confronted dilemmas as they became aware that how they wanted to proceed with implementation was at odds with the project goals and "doctrine." In the end, teachers either ignored important elements of SCISP that were not resonant with their beliefs, or transformed the curriculum to align with their traditional beliefs about the teacher's role in the science classroom which entailed controlling the direction and goals of the lessons.

Linda Cronin-Jones' (1991) naturalistic case study of two US middle school science teachers portrayed a similar influence of teacher beliefs on curriculum implementation. She found that teachers' beliefs about how students learn, teachers' role in the science classroom, the ability levels of students, and the relative importance of science topics strongly influenced teachers' translation of the intended curriculum. Although certain components of the teachers' belief structures facilitated implementation, on the whole the teachers significantly altered the curriculum to be more congruous with their existing belief structures, which were incongruous with the underlying philosophy of the intended curriculum.

Framed in terms of cultural myths, Kenneth Tobin and Campbell McRobbie (1996) examined the beliefs about teaching and learning of an experienced chemistry teacher, Jacobs. Jacobs made sense of his teaching based on four cultural myths concerning transmission of knowledge, efficiency, rigor in the curriculum, and assessment. The myths related closely to one another and were grounded in two core beliefs: (a) knowledge exists separate from the knower, and (b) the teacher should have power in enacting curriculum. The myths led to classroom practices consistent with the two core beliefs but in clear contrast to the type of instruction advocated in science reform initiatives.

These studies provide examples of the influence of teachers' beliefs on their practices in the context of curriculum reform. Specifically they paint a detailed portrait of how, when teachers' beliefs are incompatible with the philosophical underpinnings and advocated practices of reform-based curricula, implementation of

reform initiatives is compromised. On the other hand, since the publication of the *National Science Education Standards* (National Research Council [NRC] 1996) and the resultant shift in emphasis of science education toward more inquiry-centered classrooms, studies have emerged that show a more positive influence of teacher beliefs on the process of reform-oriented curriculum implementation. For example, in a study by Karen Levitt (2001), it was found that the majority of the 16 US elementary teachers from two school districts involved in a local systemic science education reform initiative (called ASSET) held beliefs and demonstrated practices that were consistent with recommendations for teaching and learning science as described in the *National Science Education Standards* (NRC 1996) and facilitated curriculum reform. Moreover, Levitt concluded that in the process of implementing a program of science education reform, beliefs and practices changed in a reciprocal way; that is, not only did teachers' beliefs have a positive influence on curriculum implementation, but the process of implementing the reform-based practices of the ASSET program had a positive influence on some of the teachers' espoused beliefs.

Similarly, Barbara Crawford (2007) found that the US prospective teachers in her study who exhibited the firmest beliefs aligned with a goal of engaging students in inquiry were able to enact those views in their practice, even in the face of "the rough and tumble of practice" (p. 613). She concluded that prospective teachers' belief systems, including epistemological beliefs about science, may well serve as the most critical factor influencing his or her ability and intentions to teach science as inquiry, even more influential than cultural obstacles (e.g., resistant student, mandated curriculum).

The Role of Context and Teacher Beliefs

The role of science teachers' beliefs is significant to curriculum implementation and cannot be overlooked or minimized in the process of curricular change and innovation. However, as many studies suggest, there inevitably exists contextual factors that have a mediating influence on teachers' beliefs in the process of curriculum implementation. As science education studies have documented the influence of teacher beliefs on curriculum reform, studies also have emerged that focus on the role of contextual constraints and demands on teachers' beliefs, practices, and implementation of reform-based curricula (e.g., Haney and McArthur 2002). The context of the teacher includes how the teacher perceives his/her world as well as the teaching conditions that teachers must negotiate on a daily basis. Specifically, these studies have shown that teaching practices associated with positivist/empiricist epistemologies resonate with a number of external teaching conditions that rarely challenge teachers' epistemological beliefs: strict accountability, a culture of time efficiency, mandatory curricula, state and national assessments, teacher socialization. Randy Yerrick and colleagues (1997) asserted that these external conditions may influence teachers to the point that they simply resist thinking about content and teaching in any other way. Even when teachers hold private, individual beliefs

that align with constructivist-oriented epistemologies, such conditions often become the mediating factor in teachers' decision making. In these cases, teachers face a difficult conundrum in reconciling what they believe about science teaching and learning with the powerful influence of the constraints that they encountered in the school culture.

"Incongruity" Thesis

Just as there are studies that support the influence of teachers' espoused beliefs on their practices, a competing set of studies exist that demonstrate that *teachers' espoused beliefs do not necessarily influence their actions.* These studies by and large portray teachers who espouse beliefs that are congruous with philosophical underpinnings of reform but are incongruous with their observed teaching practices.

In one of the most comprehensive and long-term studies on science teacher beliefs to date, researchers from nine different US institutions in the Salish I consortium conducted a 3-year investigation of the beliefs and practices of 116 beginning teachers as related to their philosophical beliefs about teaching and their content pedagogical skills. One report from this study (Simmons et al. 1999) focused on 69 participants and showed that overall beginning teachers' espoused beliefs were incongruous with their teaching practices. Specifically, beginning teachers espoused student-centered beliefs and described their teaching practices as very student-centered. However, observational data portrayed a set of teaching practices that starkly contrasted with the teachers' beliefs.

Kang and Wallace (2004) profiled the epistemological beliefs and practices of three US experienced secondary science teachers and concluded that beliefs do not necessarily have a direct causal bearing on teachers' actions. They found that while two teachers who held naïve epistemological beliefs tended to practice in ways that resonated with those beliefs, one teacher who held sophisticated epistemological beliefs about science did not demonstrate instructional practices clearly connected to those beliefs. While the teacher espoused a view of "real science as scientists' tentative explanations validated through rigorous inquiry processes; truths of scientific explanations depend on contexts" (Kang and Wallace 2004, p. 148), he completely separated "real science" from school science and the science teaching context, and therefore did not fully apply his sophisticated epistemological beliefs to his teaching practices.

Vicente Mellado (1998) also found that there is not a clear and direct correspondence between teachers' beliefs and practices. He examined the beliefs and practices of two prospective primary teachers and two prospective secondary teachers who completed their studies at the University Extremadura in Badajoz, Spain. Mellado found that while their espoused beliefs reflected an apparent constructivist orientation toward learning, their observed teaching practices reflected little to no correspondence to these beliefs. In one of the cases in particular, the teacher, Ana, espoused beliefs that were not completely recognized in practice predominantly because her espoused beliefs were epistemologically naïve.

The underdeveloped, naïve nature of teachers' beliefs is a recurring theme in science education literature on prospective teachers' beliefs, particularly in those who espouse beliefs regarding a discovery approach to students' ideas. These teachers tend to believe that children's ideas are valuable simply because they are the children's ideas (Mellado 1998). When prospective teachers espouse beliefs about the active learner roles in which students express their ideas, their beliefs often lacked the attention to the role of students' ideas in reasoning, explaining, and making sense of science phenomena. For example, in a recent study by Yesdan Boz and Esen Uzuntiryaki (2006), 12 Turkish prospective secondary teachers espoused beliefs about chemistry teaching and learning that included a belief that group work and interaction among students in chemistry lessons should involve students in the learning process. However, when asked to describe specifically how students would be involved in the learning process, the teachers' explanations were limited to vague statements about understanding what students think, allowing students to express their views, and learning from each other.

Change in Beliefs: The Influence of Teacher Education Programs on Prospective Science Teacher Beliefs

Research has shown that prospective science teachers' beliefs are formed from years of experience as a science learner, an observer of the profession, and a participant in education courses, as well as from limited experiences as a science teaching professional (e.g., teaching in a practicum, tutoring). Through years of these experiences, prospective teachers have encountered and consumed implicit and explicit messages and images from which they form beliefs that influence their future practice – beliefs about the nature of science, how students learn, what constitutes effective science teaching, the teacher's and students' roles in the science classroom and various other aspects of schooling (Eick and Reed 2002). Prior to their teacher education, many prospective science teachers often have not been exposed to more contemporary educational theory that promotes a view of learning as generative and revisionary in nature. However, as teachers have been entering preparation programs over the last two decades, they have been confronting their largely empiricist, transmission, and absorptionist beliefs vis-à-vis constructivist epistemology and teaching. Nonetheless, conflicting findings have been reported about the influence that experiences in teacher education programs have on teacher thinking and learning to teach science.

For example, in one of a set of studies conducted by a group from the University of Wisconsin-Madison (UWM), Helen Meyer and colleagues (1999) examined prospective elementary teachers' beliefs about science, learning science, and teaching science, and how these beliefs developed over the course of a teacher preparation program that emphasized conceptual change teaching. The three teachers profiled in the study entered the program espousing beliefs about learning in which the learners' role was to receive knowledge presented from other sources. All three teachers made progress in revising their beliefs in the direction of the goals of the program.

However, their progress was dependent upon their individual beliefs about science and science learning. Furthermore, the progress that they made in developing practices that aligned with the program was found to differ among the prospective teachers. In one case, the teacher was hampered by her lack of knowledge of alternative teaching approaches and not having a solid content knowledge base. In another case, there was a mismatch between the teachers' espoused beliefs and classroom practices that reflected her ongoing struggle during the year as she reconciled the tensions between her beliefs and the reality of her teaching.

In another study conducted by the UWM group, John Lemberger et al. (1999) reported on three prospective secondary teachers' beliefs and practices through their teacher preparation program. The prospective secondary teachers entered the program with positivist beliefs about science and transmission beliefs about science teaching and learning. In addition, they believed that the overriding responsibility of the teacher was to ensure that students left instruction with the correct scientific answer, a belief that aligned with their empiricist view of science as an authoritative set of facts. These initial views of teaching science remained a "high-status" conception for the teacher throughout the program. Nonetheless, as the teachers completed the teacher education program, they demonstrated elements of more student-centered beliefs about science teaching and learning. The researchers noted that as teachers exited the preparation program, they were still struggling with the conflict between positivist beliefs about knowledge and transmission beliefs about teaching versus conceptual change teaching.

Keith Skamp and Andrea Mueller (2001) found that 12 Canadian preservice science teachers' beliefs about learning science at the entry of the program were characteristic of discovery learning and process teaching approaches. That is, they believed that students learn by engaging in science instruction, but the nature of that engagement was often limited to working with physical manipulatives ("hands-on" science). Handling concrete materials, in turn, would lead to something that the student would discover and remember. Furthermore, despite the constructivism emphasis of their 2-year postgraduate science teacher education program, the prospective teachers did not change their discovery learning framework of beliefs about science teaching and how students learn, and even slightly expanded those beliefs. The researchers noted that these findings were similar to an earlier study of the beliefs of nine Australian student teachers conducted by Skamp (1995). While student teachers indicated that additional beliefs about effective primary science teaching emerged, they overall maintained their entry beliefs about teaching and learning.

The Maryland Collaborative for Teacher Preparation (MCTP) is an example of a program that reported a significant positive influence on prospective teachers' beliefs about science and science teaching. In a study conducted by Randy McGinnis and colleagues (2002), the attitudes toward and beliefs about mathematics and science of more than 200 prospective teachers were traced over a 2.5-year period. The landscape of teachers' beliefs that evolved over the MCTP program showed that their beliefs moved substantially and significantly in the direction compatible with the guiding principles of the MCTP program, including "mathematics and science

for all, the use of cooperative learning, the use of technology to enhance instruction, the fundamental importance of problem solving, and the view that the disciplines are human endeavors open to revision" (p. 719).

Change in Beliefs: The Influence of Professional Development on Teacher Beliefs

The slow pace of reform in science education has been attributed to a fundamental characteristic of teacher beliefs: beliefs are stable and highly resistant to change (Haney et al. 1996). Numerous studies have demonstrated that despite a range of professional development experience – from short summer courses to intense and sustained professional development efforts – the process of facilitating revision and change of teacher beliefs and practices is complex and not always successful. For example, in a study by Yerrick et al. (1997), teachers overall did not shift in their beliefs about the nature of scientific knowledge, teaching, and assessment, despite participating in a professional development program whose goals aligned with tenets of reform. Instead, teachers assimilated "new messages" into their initial set of fundamental beliefs. The researchers concluded that the teachers' "unshakable" beliefs kept them from understanding the merit of present-day scientific inquiry and realizing the tenets of reform.

The difficult process of facilitating teachers' change in beliefs and practices through professional development also was reflected in a study by Jari Lavonen and colleagues (2004). Finnish physics teachers who participated in a 1.5-year In-service Training for Physics Teachers (ITPT) professional development program aimed at enhancing their use of laboratory experiments developed an improved awareness of the goals of classroom experiments. In addition, the teachers reported more attention to using experiments consciously to help students construct meaning. However, while their beliefs seemed to move toward those advocated by the ITPT program, only approximately 20% of the participants enhanced their use of experiments in conjunction with the goals of the program.

Several studies have shown that specific design elements of professional development programs in science education are crucial in facilitating teachers' changes in beliefs and practices. For example, Julie Luft and colleagues (2003) examined teacher beliefs in the context of variations on traditional in-service professional development programs. Beginning secondary science teachers who participated in a *science-focused* support program held more conceptual and constructivist beliefs about student learning, implemented more inquiry-based or students-centered lessons, and felt fewer constraints in their teaching than did teachers in no induction program or a general induction program. These findings support teacher education research that has shown that subject matter focus and sustained contact are necessary for effective professional development.

Mentoring and coaching relationships have been shown to significantly and successfully facilitate the revision and refinement of science teachers' beliefs and practices, particularly in the context of participation in studies in which the teacher and

science educator were coresearchers. For example when beginning teachers participated as coresearchers in studies with Ken Tobin, they refined their beliefs and practices through iterative cycles of analysis and reflection upon what happened in their respective classrooms and ways to improve student learning (e.g., Tobin 1993). In these studies, metaphors served as an organizer for beliefs and practices and became a critical tool in facilitating the teachers' change in beliefs. While such a process was difficult, labor-intensive, and required considerable reflection on practice, the teachers noted that they became empowered and accountable for their classroom practice in the process of educational reform.

Complexity of Beliefs

Within the last decade an increasing number of studies have surfaced that focus on the complexity of beliefs. The major assertion of these studies is that when beliefs and practices are found to be incongruous, the relationship between beliefs and practices may not be so simple. These studies have demonstrated various aspects of the complexity – beliefs as clustered, nested, and competing.

Derek Cheung and Pun-Hon Ng (2000) studied the curriculum beliefs of 810 integrated science, chemistry, physics, and biology teachers in Hong Kong. One of the significant findings reported in the study indicated that science teachers' beliefs about curriculum design were held in clusters and had a hierarchical structure. They found that five curriculum orientations (academic, cognitive process, society-centered, humanistic, and technological) clustered together to form a superordinate curriculum meta-orientation. Hence, it was possible for a science teacher to hold several competing orientations. Furthermore, they asserted that the clustering effect may explain the varying degrees of incongruity between teachers' beliefs and practices seen in research.

The complexity of teachers' beliefs has also been characterized in terms of "nestedness." In an interview study of 37 Taiwanese teachers, Chin-Chung Tsai (2002) investigated teachers' espoused beliefs about science teaching, learning science, and the nature of science as traditional, process, or constructivist. He found that most science teachers held traditional beliefs across the three belief categories. Only two of the 37 teachers espoused totally divergent beliefs. Furthermore, more than half of the teachers demonstrated close alignment between their beliefs about science teaching, learning science, and the nature of science, forming a belief system that Tsai termed "nested epistemologies." Similarly, Stephen Waters-Adams (2006) found that the complex relationship among sets of beliefs influenced four English primary teachers' practices, specifically the nested nature of teachers' espoused beliefs about the nature of science and their beliefs about education, teaching, and learning.

While nested epistemologies found in Tsai's and Waters-Adams' studies tended to be experienced teachers, Lynn Bryan (2003) found substantial nesting characteristics in the belief profile of a US prospective elementary teacher. The prospective

teacher held a highly complex set of beliefs that included foundational beliefs and dualistic beliefs. One nest of beliefs was based on her vision of science teaching and reflected a student-centered, discovery approach to teaching. This nest consisted of espoused beliefs to which she developed a commitment in her teacher preparation course, but with which she had very little experience enacting in a classroom. The other nest of beliefs was well-developed, supported by years of educational experiences, and reflected a transmission view of teaching and learning. This nest of beliefs had a stronger influence on her practice during student teaching as it was resonant with her foundational beliefs about the nature of science and control in the classroom and created a strong, consistent, and self-reinforcing belief system. The nested and competing nature of beliefs described in this and other studies is resonant with psychology literature in that beliefs within a system that are incompatible or inconsistent with one another may remain so, as long as they are not examined against one another (Rokeach 1968).

Direction for Future Research

Upon reflecting on the international representation of the studies in this chapter, it was somewhat surprising that very few studies addressed the sociocultural dimensions of science teacher beliefs. As the world's population becomes more globalized and populations become more mobile, the demographics of today's classrooms are changing. Classrooms around the world are becoming more diverse. Hence, it seems incumbent upon science educators to consider the sociocultural dimensions of teacher beliefs, particularly as they come to bear on equitable science instruction, or "science for all." For example, what is the relationship between teacher beliefs about culturally diverse students, teachers' decisions and actions, and equitable science learning opportunities for students? What science teacher beliefs are likely to predict successful teaching of culturally diverse students? How do science educators facilitate teachers' change or refinement in beliefs in ways that will assist them in developing science curricula that empowers students from culturally diverse backgrounds?

One series of studies by Okhee Lee and colleagues (e.g., Lee et al. 2007) has been examining such questions, in particular elementary school teachers' beliefs and practices regarding science instruction in linguistically and culturally diverse classrooms. Overall these studies showed that changing teachers' beliefs and practices to incorporate students' cultural and linguistic experiences into science instruction is a gradual and challenging process – regardless of whether or not the teachers shared elements of their students' language and culture. Furthermore, these studies illustrate the complex and nuanced relationships among culture, language, and science learning.

Another line of research for the field of science education to consider relates to the influences of teachers' personal cultural beliefs (e.g., beliefs related to the social norms, customs, values, and social practices associated with a group of people) on science teaching decisions and actions. One example of such a study is Ping Wang's (2004) investigation of the influence of traditional Chinese cultural beliefs on science teachers' assessment practices. Wang described how in a long course of historical

development, the Chinese people have developed several cultural bond characteristics. He illustrated through an analysis of multiple cases how the unique concept of "face" and keeping face in the Chinese culture influenced teachers' decisions to implement certain assessment practices. He discussed how cultural beliefs strongly motivated the decisions and practices of the Chinese teachers, even in the era of science education reform:

> Chinese slangs, "Chu Tou De Chuan Zi Xian Lan" (the rafters that jut out rot first—one who wants to be in the fore will get into trouble) and "Shu Da Zhao Feng" (a tall tree catches the wind—a person in a high position is liable to be attacked), to name but a few, reflect the characteristic of Chinese people to fit into the crowd…. A practical representation of the above characteristics in Chinese school system is a collective mode of teaching. [Teachers] are expected to teach with the same approach and at the same pace. (pp. 103–104)

Unquestionably, all cultures have some characteristics and beliefs that distinguish them from others. An interesting and necessary line of research entails uncovering the tacit and taken-for-granted sociocultural aspects of teachers' beliefs and development of knowledge for teaching science. Specifically, what is the relationship between teachers' culture, beliefs, and practices? What are the implications of this relationship on teacher learning?

Concluding Remarks

If teachers' are expected to revise and refine their beliefs and practices, science education instruction must provide ample opportunities for teachers to articulate and confront beliefs vis-à-vis their practices and the philosophical underpinnings of reform. Both teacher educators and students of teaching need to view teaching as a process of inquiry, and view tensions as a necessary stimulus for developing professional knowledge about teaching and learning. Adopting the view that learning to teach science is analogous in many ways to learning science means taking into account that (a) teachers should engage in experiences that contribute to constructing their knowledge about teaching and learning, rather than passively receiving and accepting information; and (b) revising and refining beliefs and practices entails reflection in and on practice (Schön 1983). Science teacher educators must also recognize not only that teachers may hold beliefs that are incongruous with the philosophical underpinnings of reform initiatives, but also that they may not have well-developed knowledge to enact those beliefs (i.e., knowledge of how to use the approaches advocated in reform), as they may not have learned science themselves through the use of instructional approaches guided by these learning principles. Hence, it is essential that as science teacher educators design professional development experiences, they take into account that teachers may need to reflectively consider or reconsider principles of learning derived from research, as well as how to facilitate learning in their classrooms based on these principles.

Science teacher educators also must keep in mind that experience for the sake of experience, is not in and of itself educational. Research has shown the most educative experiences are those that provide substantial support of teacher learning: ongoing

assessment and evaluation, time and opportunities for reflection, administrative and community support, and opportunities for observing and being observed. The goal of science teacher education should be to facilitate teachers' disposition to inquiry and to systematically reflect upon their beliefs, practices, and developing knowledge. Teachers at all stages of their career trajectory must continue to challenge and refine their ideas about teaching and learning science and learn how to learn from experience. Learning to observe and analyze teaching; learning to isolate, frame, and reframe problems of practice; and learning to take action and interpret that action are skills that take time and practice to develop. Moreover, teachers' interpretations are fundamental to the process. Rather than confronting teachers with alternative conceptions and administering prescriptions for improving practice, teachers should share responsibility in their learning.

Finally, the complexity studies reviewed suggest that science teacher educators should consider addressing the system of beliefs, rather than targeting individual beliefs. Reform efforts advocate teaching science such that there is a weaving of science knowledge, the nature of science, and science processes in science instruction. Likewise, teacher educators should consider targeting prospective teachers' systems of beliefs about science knowledge, the nature of science, and science processes.

Science education reform in countries around the world advocates a view of learning science that places more of an emphasis on understanding scientific concepts and developing abilities of inquiry, using evidence and strategies for developing or revising an explanation, attending to students' active engagement and learning needs, and acknowledging that students perceive their world through the knowledge and beliefs that they hold. This view of the science classroom means not simply new sets of teacher practices, but a revised and contemporary way of thinking about science and the teaching and learning of science. The success of these reforms indisputably depends upon science teachers' capacity to integrate the epistemology and practices of reform with their beliefs and extant practices. Whether it is a process of refinement or complete revision, it is a matter of learning. Research on science learning tells us that learning begins with the existing beliefs and knowledge of learners. If gains are to be made in terms of reforming science teaching, then teacher educators must tailor instruction to address the beliefs and knowledge of those who are expected to enact the changes. Ignoring or marginalizing the role of teachers' beliefs in the process of improving science education is essentially the same as ignoring the role of students' existing beliefs and knowledge in the process of learning science.

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