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OVERVIEW OF THE ROLE OF TEACHER BELIEFS IN SCIENCE EDUCATION

INTRODUCTION TO TEACHER BELIEFS IN SCIENCE EDUCATION

The monumental shift in cognitive science from a behaviorist theory of learning to a constructivist theory of learning, taking place from the late 1960s through the late 1980s, had a profound impact on scholars' understanding of teaching and teacher thinking. The literature on teaching throughout the 1980s increasingly referred to teachers as creative and intelligent professionals who make decisions based on their own knowledge, beliefs and experiences (Richardson, 1996). Scholarly literature from the 1980s onward established the construct of teacher beliefs as a form of cognition that greatly influences what happens in classrooms. Beliefs are most often thought of as views, opinions and principles "not immediately susceptible to rigorous proof" (Dictionary.com, 2012). However, the beliefs construct as applied to science teaching has multiple meanings and is subject to interpretation. One often quoted statement about the significance of teacher beliefs to educational research was made by Pajares (1992), "[many researchers agree that] beliefs are the best indicators of the decisions individuals make throughout their lives."

The definition or specification of teacher beliefs has been a point of controversy across the years in the literature. One of the central points of the debate has been whether and how beliefs differ from knowledge (Pajares, 1992). Some scholars assert that beliefs include an affective or evaluative component not encompassed by the knowledge construct, while others have defined knowledge based on experience more broadly. Interested readers may want to read the following articles that depict the evolution of the beliefs construct over time: Bryan (2012), Green (1971), Nespor (1987), Pajares (1992), and van Driel, Beijard & Verloop (2001). Despite these differences in definitions, it is well accepted by researchers that teacher beliefs have a powerful impact on science teaching and learning. Research over the past three decades has resulted in a set of assumptions about the nature of teacher beliefs that are widely accepted (Bryan, 2012). These include:

1. Beliefs are far more influential than academic knowledge in framing, analyzing and solving problems and making teaching decisions.
2. Some beliefs are more strongly held than others, resulting in "core" and "peripheral" beliefs. An individual's core beliefs may be more resistant to change.

R. Evans et al., (Eds.), The Role of Science Teachers' Beliefs in International Classrooms, 17–31.

3. Beliefs do not exist independently of one another, but are arranged in an ecology, or an "internal architecture" of systems that have psychological importance to the individual.
4. Individuals may have competing belief sets about the same topic.
5. When one belief is changed, it is likely to affect other beliefs throughout the system.
6. Some scholars posit that belief systems occur in "nests" (Bryan, 2003) or sets of beliefs, including core and peripheral beliefs about various principles that are linked or grouped together.

In science education, a landmark study by Munby (1984) solidified the importance of teacher beliefs to practices. Munby recognized that teachers are not likely to be convinced to adopt innovative teaching strategies based solely on scientific evidence from research studies. Rather, teachers will take on the important role of interpreting the innovation and evaluating its efficacy for their particular students. Munby asserted, "Importantly, part of a teacher's context which is evidently significant to adopting research findings or implementing curricula is what a teacher believes . . . (1984, p. 28)." Using repertory grid analysis (see Kelly, 1955) and a series of iterative interviews and observations, Munby concluded that the participant teacher in his study, Ellen, had deep seated beliefs that guided her practice. These included: (a) helping students cope with new information and learn independently; (b) increasing student confidence; and (c) helping students learn concepts in the earth science curriculum which she thought were valuable for their everyday lives. Ellen's orientation to teaching was pragmatic rather than theoretical. Munby concluded that Ellen would review and filter new curriculum innovations for those that were resonate with her core beliefs.

The ideas of Nespor (1987), while not specific to science education, have often been adopted by science educators researching teacher beliefs. Nepor's early work helped establish beliefs as a theoretical construct and asserted that teachers rely on their core belief systems rather than academic knowledge when determining classroom actions. Nespor noted that the rapid pace and ill-structured nature of educational environments promotes decision making based on core affective elements and evaluations rather than step-by-step problem solving. He posited that beliefs are made up of: (a) episodic knowledge, characterized by remembered stories and events; (b) affective elements, such as feelings about students, and (c) "existential presumptions," or beliefs about the existence or nonexistence of categorical entities, such as "brightness," "immaturity," "ability" and "laziness." Nespor views teacher beliefs as an integration of knowledge and feelings built up largely through teaching experience.

Van Driel and colleagues (van Driel, Beijard & Verloop, 2001) published a cognitive framework for science teaching in which they depicted beliefs as a subset of teachers' practical knowledge. Along with beliefs as influential determiners of classroom practice, they characterized teachers' practical knowledge as being action-oriented, personal and context-bound, tacit and integrated. Van Driel and colleagues

asserted that beliefs act as a "filter" through which newly acquired information is passed before it is integrated into the knowledge base. The idea of beliefs as a filter for knowledge is similar to Munby's (1984) original assertion that teachers will search for aspects of reform-based practice that are compatible with their core beliefs.

A fourth foundational study on the relationship between teacher beliefs and intentions to implement reform-based teaching (Haney, Czerniak & Lumpe, 1996) employed theory and mathematical modeling from educational psychology. Haney and colleagues posited that the intention to implement reform would be a direct result of teachers' attitudes towards the reform behavior, perceived social norms in their school context, and perceived behavioral control, or an assessment of the obstacles or resources available to carry out the behavior. According to the researchers, an individual's salient beliefs lie behind her attitudes, perceptions of social norms and perceptions of behavioral control and are thus indirectly at the root of the intention to carry out reform-based teaching behavior. Survey results indicated that indeed, "teacher beliefs are significant contributors of behavioral intention" (Haney et al., 1996, p. 985). Teachers' attitudes towards reform were the greatest contributor to the model of planned intentions, while perceived behavioral control contributed moderately and perceived norms contributed very little. Since attitudes towards reform were so important, the authors asserted that developing positive attitudes could be an anchor for achieving reform. They further suggested that feelings of self-efficacy or success with reform-based teaching experiences might foster positive attitudes about reform.

EXPERIENCED SCIENCE TEACHER BELIEFS AND THEIR INFLUENCE ON TEACHING

Experienced science teachers have had years to build their belief systems which tend to be complex, integrated and quite stable (Bryan, 2012; Wallace & Kang, 2004; van Driel, Bulte & Verloop, 2005; Wallace & Priestley, 2011). One area of particular interest to researchers has been whether teachers have beliefs that support or impede the implementation of reform-based instruction. As a representative example, van Driel and colleagues (2005), researched teachers' beliefs about and intentions to implement a reform-based chemistry curriculum in the Netherlands. They found that although many teachers had mixed beliefs, some teachers fell squarely into either traditional or reform-based factions. Across the entire sample, there was roughly equal support for the traditional and reform-based curricula. The authors implied that curriculum structures should be flexible enough to allow for teacher choice in implementing curriculum in accordance with their beliefs, since these are strongly held and likely to remain stable.

Core Teacher Beliefs Guide Practice

Many studies have indicated congruence or close correspondence between teachers' espoused beliefs about reform, whether positive or negative, and their classroom

practices (see Bryan, 2012). Historically, when reform-based interventions are at odds with teacher beliefs, teachers either refuse to implement these reforms or do so superficially (Cotton, 2006; Cronin-Jones, 1991; Olson, 1981; Yerrick, Parke & Nugent, 1997). For example, Cronin-Jones (1991) conducted two case studies of middle grades teachers implementing an innovative constructivist-based science curriculum. She found that both teachers held strong beliefs that students of this age group need explicit direction, learn best through repeated drill and practice, and that factual content acquisition is the most important goal of science education. Both teachers converted the curriculum guidelines into more superficial instructional activities that matched their beliefs about students and science education. Cotton (2006) found that Canadian secondary science teachers rejected the implementation of a value-based environmental science curriculum because of their strong beliefs that education should be value-neutral, allowing children to form their own opinions. Yerrick et al. (1997) documented that teachers constructed rational arguments to describe their implementation of a reform-based curriculum when talking to the project researchers, when in fact they continued to teach in traditional ways.

In a few studies, when teachers' beliefs coincided with the philosophy of the reforms, they worked enthusiastically to promote the reforms (Levitt, 2001; Wallace & Priestley, 2011). Levitt studied the practices of 16 elementary teachers and found that overall they supported reform-based science instruction because it resonated with their ideas about the importance of student-centered curricula. A study of experienced secondary teachers in Scotland indicated that when teachers held positive beliefs about the general principles behind a government-led formative assessment initiative, they not only implemented the reform strategies, but invented ones of their own (Wallace & Priestley, 2011).

Experienced teachers hold a variety of views about reform (van Driel et al., 2005) and may assert their own beliefs when these are at odds with school policy or social culture. A study of Scottish college biology teachers (equivalent to the community college level in the U. S., Priestley, Edwards, Priestley & Miller, 2012) showed that teachers' positive beliefs about reform were indeed associated with the commitment to assert personal teacher agency, rather than follow the school policy of teaching for test performance. One participant in their study was content to have his students achieve high test scores and did not particularly value the types of outcomes, such as collaboration and connectedness, associated with constructivist-based teaching. This participant had no desire to implement reform-based strategies and therefore maintained the status quo of traditional instruction supported by the school administration. A second participant, who did value the outcomes associated with constructivist-based learning, implemented more student-centered strategies and thus took a risk in asserting her beliefs in opposition to what was valued by school management.

Some studies, however, have indicated that there are often more complex relationships between beliefs and practices, including mismatches between espoused beliefs and observed instruction. Although this phenomenon is found more commonly

with preservice teachers, experienced teachers have also shown incongruence between their stated beliefs about the nature of science or learning epistemologies and their own classroom practices. This may be related to the phenomenon that teachers learn new ideas through professional development that appeal to them, but that these ideas are held more peripherally than their core teaching beliefs. For example, Trumbell and colleagues (Trumbell, Scarano & Bonney, 2006) found that two participant middle school teachers both espoused reform-based tenets about the nature of science, which they learned superficially in their graduate coursework. However, neither teacher enacted these inquiry-based aspects of science in their classrooms early in their study. Similarly, three participant primary teachers in Waters-Adams (2006) study held moderately traditional hypo-deductive views of the nature of science, but taught science largely through stating facts. Interestingly, in both of these qualitative studies, one or more of the teachers began to change their beliefs during the study and they will be referred to again in the section on belief change below.

Tension between Teachers' Reform-based Beliefs and School Policy

The theme that some teachers hold very positive beliefs about reform-based teaching, but feel thwarted from implementing these in school culture is emerging as an area of policy concern in many school subjects, of which science is one example. Top-down educational polices and their accompanying discourses have been documented to interrupt "productive pedagogies" that might have focused on more real-world connections, questioning and investigation (Lingard, 2005). This phenomenon has been explored most thoroughly in the United Kingdom and the United States (Au, 2006; Ball, 2003; Hursh, 2007; Lingard, 2005; Ranson, 2003). Powerful political structures including federal and state laws (for example in the U. S.), district level administrations, building administrations and master teacher managers enforce adherence to teaching the mandated curriculum in preparation for standardized tests. Within this climate, teachers are expected to produce high test scores at the expense of other educational values, such as critical thinking or the deep exploration of concepts.

Some studies have indicated that teachers may hold sophisticated views of the nature of science or learning epistemologies, but do not use them extensively when planning and teaching their students. Wallace and Kang (2004) found that a group of high school science teachers held competing beliefs about inquiry-based science. The teachers held private belief sets that included enthusiastic attitudes towards inquiry-based teaching. The teachers felt that inquiry engaged students, developed problem solving skills and promoted autonomous thinking. The teachers confided to the researchers that they would use inquiry much more if it did not conflict with the mandated curriculum. In more public settings, the teachers espoused their public belief sets, in which they supported other methods of teaching concepts and reinforcing these through verification labs.

Another example of the tension between positive beliefs about reform-based teaching and accountability pressures was documented by Wallace (2013), a veteran science educator who returned to the classroom in 2005-2006 to experience teaching high school biology in the contemporary educational context of mandated testing. She found that teaching science through inquiry-based methods promoted student questioning, divergent thinking and often open-ended learning outcomes. Divergent thinking as an educational goal stood in direct contrast to the overall cultural goal of the school for producing correct and convergent answers on standardized tests. These dual and opposing purposes of science teaching created a difficult context within which Wallace could enact her constructivist-based teaching beliefs.

Rop (2002) also reported on this tension when he studied the discourse in the classroom of a veteran chemistry teacher. While the teacher valued students' inquiry questions, he did not devote classroom time to investigating these questions. Rop (2002) noted that powerful and conflicting pressures come into play in the everyday patterns of classroom discourse. The teacher felt that the students' questions interrupted the flow of discourse necessary to teach the mandated curriculum. Rop asserted that science educators need to take seriously the juxtaposition between management expectations for content coverage and teachers' desire to honor student-centered inquiry (Rop, 2002). Teachers feel real pressure from structural and cultural influences in the ecology of school. Studies of the ways that policies thwart teacher agency, therefore, suggest that having positive beliefs about reform might be necessary, but not sufficient to affect reform-based strategies in the classroom.

In contrast, some earlier studies indicated that experienced science teachers generally held positive beliefs about their self-efficacy and intentions to enact reform-based teaching. These studies indicated that teachers in general believed in their own ability to influence learning outcomes, their personal agency in being able to carry out effective learning and to control many aspects of their teaching context (Lumpe, Haney & Czerniak, 2000). Some reasons for this discrepancy may be that: (a) these earlier studies pre-date strict enforcement by schools of accountability policies, such as the "No Child Left Behind" legislation in the United States; and (b) the idea that self-efficacy beliefs research uses different theoretical paradigms including psychology of the individual, rather than socio-cultural studies which emphasize a teacher's interaction with others. It would be interesting for researchers to repeat some of the studies of teachers' self-efficacy beliefs (Haney, Czerniak & Lumpe, 1996; Lumpey, Haney & Czerniak, 2000; Enochs, Scharmann & Riggs, 1995) in the current political climate of accountability and standardized testing. This line of research might further elucidate the significance of the role of school policy in regards to how teachers may choose to enact or not enact practice consistent with their beliefs.

In summary, experienced science teachers have belief sets that are stable, closely held and resistant to change. Experienced teachers have a wide range of opinions about the value of reform-based instructional strategies. Teachers most often enact

science instruction that is aligned with their core beliefs, whether these represent positive or negative attitudes towards reform. Beliefs often act as a cognitive filter for teachers as they select particular aspects of reform-based instruction to implement. In some cases, teachers adopt new ideas about topics such as the nature of science or learning epistemologies, but these are not easily integrated into their core belief sets or teaching practices. The phenomenon of science teachers having positive beliefs about the value of reform-based teaching, but finding it difficult to enact these reforms in school cultures of accountability can be a significant barrier to overcoming traditional practice.

The Possibility for Change in Experienced Teachers' Beliefs

Because teacher beliefs are so crucial to practice and intentions to enact reform-based teaching, some researchers have examined whether professional development opportunities can change teacher beliefs. Researchers in this line of investigation have examined whether professional development classes or on-site activities result in modifications to science teaching beliefs and/or practice. These scholars have tried to explain the complex relationships among learning, teaching and belief change.

In one study (Lavonen, Jauhiainen, Koponen & Kurki-Suonio, 2004), experienced physics teachers in Finland participated in a one and one-half year professional development program that emphasized the use of lab work in physics. The designers of the program sought to change teachers beliefs about the ways labs might be used to foster conceptual development. They sought to develop teachers' ideas that lab work could be used to build students' epistemic knowledge of physics by emphasizing that laboratory observations should be interpreted against the background of socially constructed theory, rather than used as empirical "proof" that theory is correct. The results of the study indicated that only about 20% of the teachers in the treatment group changed their fundamental beliefs about the purpose of lab work in physics. However, most of the teachers indicated that they paid more attention to the goals of their labs and took more care planning their labs than before the intervention. The Lavonen et al. study (2004) indicates that experienced teacher belief change is difficult, even with well-planned and extensive inservice education.

A study by Trumbell, Scarano and Bonney (2006) illustrates how teachers' core beliefs can influence both classroom practice and belief change. The researchers investigated the teaching and nature of science beliefs for two veteran middle school teachers involved in professional development program to support the implementation of inquiry in the classroom. Both teachers carried out inquiry-based projects with their students and both struggled with how to structure these in their life science classes. One participant, Natalie espoused beliefs about the nature of science that were largely in line with reform-based views, however, she enacted a superficial version of inquiry. Her beliefs in the importance of structure, clarity and the direct transmission of knowledge limited her willingness to let students

ask questions or be confused. One core element of her belief structure appeared to be her reluctance to let her students make any mistakes; "she seemed to lack faith in her students' ability to learn" (Trumbell et al., 2006, p. 1741). Natalie's beliefs about science teaching and learning remained static over the three years of the study.

In contrast, the second participant, Meryl, was willing to accept uncertainty and "messiness" in science instruction. She continued to try various inquiry approaches over the course of the study. Meryl approached teaching as research, consistently trying out innovations, gathering feedback and adjusting instruction. The willingness to learn from instructional experimentation may be of central importance for the possibility of teacher belief change. Meryl's teaching practices and beliefs about the nature of science gradually changed in a parallel fashion. Her inquiry-based teaching evolved over the course of the study until both she and her students were confident in doing fairly sophisticated projects. Meryl's beliefs about the nature of science also changed towards an understanding that science is a thinking process more than a discovery of facts.

Waters-Adams (2006) also investigated the relationship between nature of science understandings and science teaching beliefs for four primary grades (children aged 4-6) teachers in England in a year-long qualitative study. The teachers were concomitantly engaged with conducting action research on their own practice. All four of the teachers initially described science as having a hypothetico-deductive epistemology, in which scientific process or problem-solving skills are used to generate and test hypotheses. However, at the beginning of the study three of the teachers' science instruction was conceptually unfocused and characterized by the transmission of facts. Thus, for three of the teachers there was a disconnect between what they thought science was like and how they taught science with none of the teachers exhibiting inquiry-based science. At the same time, all four teachers held strong beliefs that young children should learn through active engagement, inquiry, exploration and induction. They believed that the teacher should take on the role of facilitator in these endeavors. Through their action research and reflection, the teachers explored how their teaching practices articulated with their views of science. As they began to teach science utilizing their core beliefs about young children, rather than their nature of science views, their instruction became more exploratory and inductive in nature.

To summarize, several researchers have been interested in promoting more accurate views of science as inquiry among experienced teachers and connecting these ideas to classroom actions. Although teachers' core beliefs are resistant to change, two routes to belief and practice change have emerged from this research. First, making teachers aware of core beliefs they already hold that may support reform (e.g. a belief in child-centered instruction or that children can learn from their mistakes) may foster changes in practice that align with exploration and inquiry. Second, the research indicates that teacher action research and reflection over a long period of time holds promise for fostering more deeply rooted change.

PRESERVICE OR NOVICE TEACHER BELIEFS AND THEIR INFLUENCE ON TEACHING

Research suggests that beginning teachers' practices are often related to their needs to keep students managed and engaged, regardless of their beliefs about the most effective forms of science instruction. Talanquer and colleagues (Talanquer, Novodvorsky & Tomanek, 2010) found that beginning science teachers in their Southwestern U. S. study selected activities that were almost always driven by one of the following goals: (a) motivating students; (b) developing science process skills; or (c) engaging students in structured science activities. The authors posited that the early adoption of these goals can lead to the construction of a belief set that prioritizes minimizing disruption over conceptual learning. The findings of the Talanquer study echo those of a previous study by Enochs and colleagues (Enochs, Scharmann & Riggs, 1995) in which preservice elementary teachers self-efficacy beliefs about teaching science were significantly related to their beliefs about pupil control, in addition to their background science preparation and self-perception of effective science teaching.

Instability of Novice Science Teachers' Beliefs

In contrast to experienced teachers, research on preservice or novice science teachers often indicates that their belief systems are disconnected, not well developed and unstable. Novice teachers may hold many competing belief sets which change or "wobble" (Simmons, Emory, Carter, Coker, Finnegan & Crockett, 1999) frequently. Simmons and her colleagues studied the beliefs of 116 beginning science teachers who had recently graduated from 10 different universities in the U. S. They found that the vast majority of these beginning teachers' beliefs "wobbled" between more teacher-centered and more student-centered beliefs about what students should be doing in the classroom. Although the new teachers viewed their own teaching as decidedly student-centered, their actual teaching practices were predominantly teacher-centered.

Yilman-Tuzman and Topcu (2008) investigated the inter-relationships among epistemological beliefs, epistemological world views and self-efficacy beliefs of 429 Turkish science preservice teachers. They found that the teachers' epistemological beliefs were not well-developed and that their survey scores for different aspects of epistemology varied widely. For example, the participants held sophisticated beliefs about the epistemological dimension "innate ability." That is, the teachers largely exhibited the view that children's intelligence is not fixed and can be developed through good teaching practices. However, their epistemological understandings of "simple knowledge," whether there can be more than one right answer, and "certain knowledge," whether knowledge is fixed, were much less sophisticated. The participants held positive beliefs about teaching with student-centered strategies, but also voiced their strong preference for having students memorize facts. The

preference for memorization was found in all of the teachers, regardless of their self-efficacy beliefs.

Similarly, Luft and her colleagues (Luft, Firestone, Wong, Ortega, Adams & Bang, 2011) found that science teachers within the first three years of service held unstable beliefs about student-centered versus teacher-centered learning. Most of their participants held more teacher-centered views when beginning their first year, although these changed somewhat during the second year towards more student-centered beliefs, especially for those in science specific professional development groups. Interestingly, during the third year, the teachers' beliefs tended to shift back towards a more teacher-centered orientation. However, those who received science specific professional development support continued to implement more student-centered strategies in their practice. The implication was that once these practices were in place, they continued to be used by the teachers despite their shift back towards more teacher-centered beliefs.

Therefore, some research findings suggest that the early years of teaching offer an impressionable period that provides opportunities for change in beliefs and practice. Yilman-Tuzman and Topcu (2008) suggested that learning epistemologies be directly taught in preservice teacher education courses. Luft and colleagues (2011) asserted that science specific professional development during the induction years is a key way to influence practice towards more student-centered orientations. There is also some evidence that the views of mentor teachers influence the beliefs of preservice teachers (Boz & Uzuntiryaki, 2006; Crawford, 2007) with the implication being that mentors be chosen for their positive beliefs about reform-based teaching.

Beliefs and Knowledge about Teaching Evolve Together

Another form of inconsistency between beliefs and practice arises when novice teachers espouse positive, yet peripheral, beliefs about reforms such as inquiry, yet lack understanding of the learning sciences, content knowledge or pedagogical content knowledge to carry these out reforms in the classroom. Boz and Uzuntiryaki (2006) found that most of the preservice chemistry teachers in their Turkish study failed to develop constructivist-oriented beliefs about teaching and learning during practice teaching. Even when teachers in their study espoused positive beliefs about student-centered strategies such as group work, they did not have a deep understanding of how those strategies promoted learning. The fact that most preservice teachers have experienced years of traditional science instruction is often cited as a barrier to forming more reform-based beliefs (Boz & Uzuntiryaki, 2006). Crawford (2007) asserted that preservice teacher beliefs about both science and science teaching are the most powerful influences on whether novice teachers implement inquiry-based instruction in the classroom, although these vary widely for preservice teachers. She suggests that frequent or widespread implementation of inquiry-based teaching may not be a practical expectation for novice science teachers who must learn a repertoire of teaching skills rapidly.

Veal (2004) provided an in-depth qualitative study of various factors influencing the beliefs and practices of two preservice chemistry teachers. First, he found that contexts in which the students learned chemistry greatly influenced their knowledge and beliefs. One participant had learned chemistry in an academic context, having had the opportunity to be an undergraduate research assistant. The other participant learned more about the practical applications of chemistry through her experience working in a veterinary clinic. These background contexts influenced the knowledge, beliefs and ways in which these novice teachers translated chemistry for their students in the classroom.

Further, Veal indicated that the beliefs of the two participants did change over time in concert with the development of their pedagogical content knowledge (PCK). He asserted that, "beliefs informed the practice of the participants in the classroom, and knowledge gained in the classroom informed the participants' beliefs" (Veal, 2004, p. 46). Veal suggested that the two participants' beliefs acted as a filter for the development of PCK, guiding the direction of learning through experience. This complex relationship between beliefs and PCK has important ramifications for teacher education. Veal suggests that teacher candidates could enhance their own PCK by first exploring their own knowledge assumptions, making their epistemologies about science and learning explicit, and then examining teaching applications that match those epistemologies.

In summary, preservice and novice teachers are at risk for adopting belief sets that support classroom management and reinforce practices that keep students busy. New teacher beliefs are unstable or "wobbling" beliefs and become more fixed over the first few years of teaching. This induction period may be a prime opportunity for novice teachers to explore their own epistemologies and beliefs about the nature of science and cultivate PCK that is compatible with their beliefs. Online and on-site science specific professional development activities hold promise for shaping beliefs and practices that support teaching for meaningful learning. Further research on the ways teacher educators can help new teachers unpack their epistemologies is a logical next step in this field.

CONCLUSIONS AND IMPLICATIONS FOR RESEARCH

Taken together, the studies reported on in this overview of science teacher beliefs point to a few synthesized understandings of science teacher beliefs. First, experienced teachers' core beliefs have a strong impact on both their enactment of the curriculum and their stance towards implementing reform-based practices. As well, teachers undergoing professional development may adopt new ideas about learning or the nature of science, but these are often held peripherally and are not easily integrated into their core belief sets. These findings imply that working with experienced teachers' core beliefs is a natural starting place for professional development. It may be useful for science teacher educators to help teachers unpack their core beliefs and reflect on what their own beliefs mean for practice. Little is

known about whether an increased self-awareness of one's own core beliefs and their pedagogical implications can affect belief change.

Research shows that those teachers who are responsive to reform-based teaching have underlying philosophical values about children, learning and the role of education that are broad-brushed and positive (Levitt, 2001; Wallace & Priestley, 2011; Waters-Adams, 2006). For example, reform-minded teachers tend to believe that: (a) children are capable of high level thinking; (b) learning how to learn is an important purpose of schooling; (c) promoting thinking is more important than conveying factual knowledge; (d) learning involves making mistakes; (e) curriculum should be largely student-centered; and (f) a teacher's primary role is that of facilitator of learning (Levitt, 2001; Priestley et al. 2011, Trumbell et al., 2006; Wallace & Kang, 2004; Wallace & Priestley, 2011; Waters-Adams, 2006). Making this research available to teachers through professional development activities might cause teachers to question their own core beliefs or reflect on their practices. Evoking cognitive dissonance, for example about students' capability for high-level thinking, may support teacher belief change towards reform-based teaching. Providing research on these novel approaches to professional development is an important research agenda for the field.

Second, there is evidence that both novice and experienced teachers can make lasting changes to their practices even without changing their core beliefs (Lavonen et al., 2004; Levitt, 2001; Luft et al., 2011, Waters-Adams, 2006). How and why this phenomenon has been observed is not entirely clear. It may be that incorporating particular practices into routines and teaching repertoires, even if required for coursework, can lead to their regular use. Students' positive responses to these practices may stimulate teachers to continue their use. Or perhaps, teachers using these reform-based practices are, in fact, in the process of slowly changing their beliefs. Therefore, it may be that adopting a new set of practices can lead to belief change, just as belief change can lead to new practices. This would imply that science teacher educators should focus on teaching practices that are reform-based, but also appealing to teachers for other reasons (e.g. promoting student engagement). Changes to practice may be one entry point in a cycle of belief and practice change. More research is needed to explore the complex relationship between beliefs and practices.

Third, there is a need for more research on the formation of teacher beliefs in early stages of teaching, including the induction phase (Luft et al., 2011). The research cited in this chapter indicates that the first few years of teaching are probably the most critical for the formation of reform-based teaching beliefs. If researchers could pinpoint more precisely the types of experiences and reflection that lead to positive views about reform, these could be replicated more often. In-depth, longitudinal case studies of how novice science teachers build their beliefs over time like that of Veal (2004) may useful, however, there is a complex interaction between belief sets that students have before entering teacher education programs and how teacher education shapes those beliefs (Avraamidou, 2013). The influence of mentor teachers' beliefs

on novice teacher beliefs is also an important area of study, although space precludes a discussion of this large topic here.

Finally, there is a concern that even when science teachers hold very positive beliefs about reform-based teaching, they are thwarted from enacting these in the classroom due to educational policy in the current political climate. Perhaps this situation will change with the introduction of the Next Generation Science Standards (Achieve Inc., 2013) into school culture. The implementation of reform-based standards and concomitant changes to science assessment may provide the impetus needed for bridging the research and practice gap in science education. The science education community will undoubtedly be interested in science teachers' beliefs about the new standards and their implementation.

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