9-11-2014

Science Teachers' Beliefs: Perceptions of Efficacy and the Nature of Scientific Knowledge and Knowing

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Author Note:
We would like to thank the editors of this volume and the anonymous reviewers for their constructive feedback on an earlier draft of this chapter. We also thank Clare Merlin for her feedback and invaluable editorial assistance.

As we write this chapter, teachers across the United States are preparing for their first days of school. Besides the excitement associated with teaching students who are newly energized after a long summer break, science teachers also come into the school year with a host of beliefs that may well shape the ways in which they teach and may ultimately have some bearing on their students' overall experiences with science. Although there are countless beliefs that teachers hold with regard to science, in this chapter we focus specifically on two beliefs that have received the most research attention—teachers' self-efficacy, which describes their beliefs about their capability to teach science, and their epistemic beliefs, which describe their beliefs about the nature of scientific knowledge and knowing.

Science has been described by many as one of the most difficult school subjects (Drew, 2011; Dweck, 2006; National Academies of Science, 2011). For this reason, the National Academies of Science has noted that a strong sense of competence is critical for success in science and for persistence in science-related careers. For science teachers in particular, this same robust sense of competence is required both to understand science and to teach it well, as teachers who feel incompetent in science are more likely to avoid teaching it (Grindrod, Klindworth, Martin, & Tytler, 1991; Skamp, 1995). Given the importance of competence beliefs in learning and teaching science, we focus on one of the most well-studied constructs dealing with this belief—teachers' self-efficacy for teaching science.

Besides self-efficacy, scholars and practitioners alike have documented the regrettable lack of sophistication that students have with regard to their basic scientific literacy. For example, many students in middle school believe that science is composed entirely of absolute truths (BouJaoude, 1996), and that the development of scientific knowledge leaves little room for creativity and imagination (Griffiths & Barman, 1995; Lederman & O'Malley, 1990; Smith,

Maclin, Houghton, & Hennessey, 2000). These troubling cases can be traced to teachers not understanding the complex nature of scientific knowledge well enough to communicate that level of sophistication to their students (Brickhouse, 1990; Duschl & Wright, 1989; Hashweh, 1996; Keys & Bryan, 2001). They can also be traced to institutional structures, such as an undue emphasis on testing, which can lead some science teachers to avoid teaching about the complexities of science (Brickhouse & Bodner, 1992; Munby, Cunningham, & Lock, 2000).

The development of students' deep understanding and appreciation for the complexity of science starts first with teachers. Teachers must have a deep level of understanding about the complexity of scientific knowledge. That is, they must understand that knowledge in science is connected to other fields of knowledge; that scientific knowledge is often revised with new evidence; that scientists often disagree; and that scientific knowledge must be justified with evidence from multiple sources and multiple experiments. Teachers must also possess the self-efficacy to lead their students through learning activities that model that complexity. Being able to teach in such a manner is certainly no easy task. It requires substantial skills in planning and organizing. It requires teachers to possess excellent classroom management skills, the ability to engage and motivate students, as well as the ability to connect these rich learning activities to the standards on which students will be tested. Given these issues that science teachers must grapple with, we chose to study science teachers' self-efficacy and their epistemic beliefs about science.

The Nature of Science Teachers' Beliefs

Epistemic Beliefs

Because the construct of epistemic beliefs is discussed in depth by Lunn and Walker (*this volume*), we provide a brief background to the construct and provide a deeper look into how these beliefs are relevant to science teachers in particular. Although there is no single unifying

framework that defines epistemic beliefs, models for the construct are generally either developmental in nature, emphasizing the qualitatively different stages or positions that individuals progress through, or stress the multidimensionality of the construct, in which "systems of beliefs" combine together along a number of related beliefs (for a review, see Hofer and Pintrich, 1997). In this chapter, because we focus on teachers' epistemic beliefs about science, we define the construct as the beliefs that teachers hold about the nature of scientific knowledge and knowing. In line with Hofer and Pintrich (1997), we see epistemic beliefs as consisting of multiple, somewhat independently operating dimensions. This means that science teachers are able to believe, for example, that scientific knowledge comes predominantly from a knowledgeable "elite" (e.g., professional scientists). However, science teachers are also able to simultaneously believe that there can be multiple "right answers" to complex problems in science.

As for the multiple dimensions, for science teachers in particular, the construct refers to their beliefs about whether scientific knowledge is simple/certain (i.e. does scientific knowledge consist of isolated bits of unchanging truths or does it consist of interconnected ideas that can evolve?), whether scientific knowledge is handed down from an elite few (e.g., "real" scientists or other authorities like teachers or textbooks), and how experimental evidence and other pieces of evidence can be used to justify scientific knowledge. If, as the National Research Council (2011) recommended, one important goal of science education is to teach students to critically think about pressing scientific issues, then teachers also need to possess the sophisticated beliefs and competencies to engender the same level of sophistication in their students.

Teaching Self-Efficacy

The self-efficacy construct, which is addressed by Siwatu (*this volume*), is especially relevant to science teachers, because science is often seen as a difficult subject for students to learn and for teachers to teach (Bursal, 2010; Buss, 2010; Drew, 2011; Johnstone, 1991). In general, self-efficacious teachers reflect on their experiences more adaptively, plan and organize more effectively, are more likely to employ and seek out engaging instructional strategies, put forth greater effort in motivating their students, and are more resilient when faced by obstacles than are teachers with lower self-efficacy (Tschannen-Moran, Woolfolk Hoy, & Hoy, 1998; Woolfolk Hoy & Davis, 2006). Given these benefits, researchers have begun to turn their attention toward the sources underlying teachers' self-efficacy beliefs (Usher & Pajares, 2008). Bandura (1997) identified four sources of capability-related information: (a) *mastery experiences*, or individuals' interpretations of their past performances, (b) *vicarious experiences*, in which individuals witness the successes and failures of others performing a task (c) *social persuasions*, the messages that individuals receive about their capabilities, and (d) *physiological and affective states*, including stress, fatigue, anxiety, and mood. In this chapter, we review the literature on the sources and benefits of teachers' self-efficacy beliefs specifically for those who teach science in elementary and secondary settings.

Research on Science Teachers' Beliefs

Epistemic Beliefs

Given researchers' and policymakers' focus on teachers' epistemic beliefs about science, we discuss the correlates of teachers' epistemic beliefs as well as the variety of factors that influence the relationship between teachers' epistemic beliefs and practices. In exploring the factors that moderate the relationship between epistemic beliefs and practices, we report on those factors that appeared in the literature most often.

Correlates of science teachers' epistemic beliefs. Teacher educators and educational psychologists would like to assume that beliefs translate into specific practices. However, the empirical evidence for this claim is mixed (Tobin, Tippins, & Gallard, 1994). On the one hand, Tsai (2006) showed that Taiwanese science teachers with more simplistic epistemic beliefs tended to focus their students' attention on test scores. They also dedicated more instructional time to teacher-directed lectures, tutorials, and exams. However, teachers with more constructivist epistemic beliefs tended to dedicate more time toward inquiry-oriented activities for their students and interactive discussions during class time. This suggests that teachers with more constructivist beliefs—those who believe that scientific knowledge is not just a collection of isolated facts, or that experiments are used merely to recreate what others have found—treat students as active co-constructors of knowledge. Teachers with more simplistic beliefs about scientific knowledge viewed students as more passive, and held the belief that knowledge should be transferred from teachers to students. In addition, Kang and Wallace (2004) found that teachers with simplistic beliefs about science tended to teach by transmitting information to students and using demonstrations as a way to illustrate a scientific concept rather than using demonstrations in a more inquiry-oriented fashion.

On the other hand, beliefs about the simple nature of science do not always translate into simplistic teaching practices, and beliefs about the complex nature of science do not always translate into correspondingly constructivist teaching practices. Therefore, researchers have come to believe that there are a number of variables that influence the degree to which teachers' beliefs about the nature of science match their teaching practices (Bell, Lederman, & Abd-El-Khalick, 2000; Lederman, 1992; Mansour, 2013). The discussion that follows deals with some of these factors.

Factors That Modify the Relationship Between Epistemic Beliefs and Practice

Mansour (2013), in a study with Egyptian teachers, found that, although there was a high degree of consistency between the belief in a simplistic nature of science and practices that reflected that simplistic notion, there was less consistency between constructivist beliefs and constructivist practices. Mansour posited that the dissimilarity in the degree of consistency between constructivist beliefs and constructivist practices resulted because forces greater than individual teachers (e.g., the Egyptian examination system) constrained teachers' beliefs in their ability to teach in a constructivist manner. In the same respect, Kang and Wallace (2004) found that, although teachers with simplistic beliefs did display practices aligned with these beliefs, teachers with more constructivist beliefs did not always teach in constructivist ways. Whether these constructivist practices emerged or not seemed more dependent on school context variables and other teacher beliefs. For example, being constrained by having to teach material for tests was hypothesized to exert an influence on whether constructivist teachers' beliefs translated into practices that reflected that belief.

In another study, Waters-Adams (2006) found that, at the start of his observations, there was very little correspondence between science teachers' beliefs about the nature of science and their practice. However, by the end of Waters-Adams's observations, these science teachers had "become more confident in their science teaching, displaying an ease that was not there before" (p. 930). These science teachers, therefore, began developing the self-efficacy to teach science in a way that aligned with certain aspects of what they believed was the most effective way to teach students. Although many of these teachers did hold simplistic beliefs that science knowledge was mostly a body of facts, the teachers ended up teaching in a much more constructivist manner because they held the belief that these scientific facts needed to be

uncovered by the students themselves rather than dispensed by the teachers. It was not until these teachers developed the self-efficacy to implement the appropriate pedagogical strategies, however, that these constructivist practices became evident. One of Waters-Adams's key implications was that student-teachers need to understand the nature of science, but they also need opportunities to enact their practices and observe their effects within a classroom. We posit that this aspect of student-teachers' development—the opportunity to observe and reflect on how certain pedagogical strategies result in corresponding student outcomes—serves as a way to bolster teachers' self-efficacy to teach science in a constructivist manner. We discuss this in more depth later.

Besides the studies mentioned above, others have found that the amount of support provided in a classroom can modify the relationship. For example, Stofflett (1994) showed that preservice teachers were less likely to translate their constructivist beliefs into corresponding practices if their cooperating teachers were unsupportive of it. Kaufman and Moss (2010) found that, unless teachers were able to maintain order and control in their classrooms, their constructivist beliefs were unlikely to be manifested in their practices. Therefore, as we describe in more depth later, unless teachers believe that they have the capabilities to implement inquiry science, their beliefs about the nature of science are not likely to translate into constructivist practices. Science teachers' self-efficacy beliefs, therefore, are the subject of the next section.

Self-Efficacy

In this section we describe the antecedents and potential benefits of science teachers' self-efficacy. In particular, we describe (a) the relationship between teacher's self-efficacy and their effectiveness, (b) the sources of these beliefs, and (c) the role of context in the development and maintenance of science teachers' self-efficacy beliefs. These themes have been the focus of

much research because theory, teacher education, and professional development may be advanced by a better understanding of where these beliefs come from, how contextual factors influence them, and what influence they have on teacher quality and student achievement.

Influence on teacher effectiveness. In the domain of science, researchers have found that long-term research-based professional development programs have improved elementary teachers' science self-efficacy and increased both the instructional time they spend on science and their use of inquiry-based, constructivist methods (Lakshmanan, Heath, Perlmutter, & Elder, 2011; Posnanski, 2002; Sandholtz & Ringstaff, 2011). Lakshmanan et al. (2011) reported that science self-efficacy was moderately correlated with use of inquiry-based methods. However, none of these studies provided evidence that self-efficacy mediated the relationship between professional development and teacher behaviors. That is, more research is needed to document a causal link between science teachers' self-efficacy beliefs and their adoption of inquiry-based methods or increases in the amount of time they dedicated to teaching science.

It is also difficult to establish the existence of a causal relationship between self-efficacy and student achievement, particularly with regard to science. Lumpe, Czerniak, Haney, and Beltyukova (2012) found a significant and positive relationship between elementary teachers' science self-efficacy and the performance of both fourth and sixth grade students on science achievement tests. Angle and Moseley (2009), on the other hand, reported that, although self-efficacious high school teachers tended to believe that their students were well-prepared for a recently developed End-of-Instruction Biology 1 test, their students were no more likely to score at a proficient level on the test. That is, they found science teaching self-efficacy to be unrelated to how students performed on a cumulative test. Although scholars have found teachers' self-efficacy and student performance to be positively associated in other subject areas (Caprara,

Barbaranelli, Steca, & Malone, 2006; Ross, Hogaboam-Gray, & Hannay, 2001), it is clear that the relationship between teachers' beliefs and students' outcomes is complex. Inferences drawn from such studies are not complete without a careful consideration of the factors that may mediate the relationship between science teachers' self-efficacy beliefs, their behaviors, and the behaviors of their students. Moreover, standardized tests are often a poor proxy for student learning (Braun, Chudowsky, & Koenig, 2010).

Sources of self-efficacy. Bandura (1997) hypothesized that self-efficacy is informed by at least four sources of information. Research on science teaching self-efficacy has focused most on the influence of *mastery experiences*, perhaps because Bandura argued that such experiences typically had the greatest effect on self-efficacy. In some studies, teaching experience has been used as a proxy for mastery experience (e.g., Cantrell, Young, & Moore, 2003; Cone, 2009). Some have documented that preservice teachers became more confident in early field experiences teaching science (Cannon & Scharmann, 1996; Cantrell, Young, & Moore, 2003; Cone, 2009). Liu, Jack, and Chiu (2007) also found that teachers who had taught science for eleven or more years had higher self-efficacy than those who had taught for ten or fewer. However, other researchers have reported no difference in teachers' science self-efficacy related to early field experiences or years of experience (Angle & Moseley, 2009; Yilmaz & Cavaz, 2008). These mixed results may reflect the fact that researchers did not account for whether these experiences were successful or not, an essential component of mastery experiences as described by Bandura (1997).

In general, positive past experiences with science and science instruction appear to have a more consistent influence on science teaching self-efficacy. For example, qualitative investigations have revealed that positive authentic science teaching experiences can be a

powerful source of self-efficacy among preservice elementary teachers (Carrier, 2009; Gunning & Mensah, 2011). Preservice teachers who were more self-efficacious were also more likely to report having past positive experiences in science as K-12 students (Bleicher, 2004; Hechter, 2011). Mansfield and Woods-McConney (2012) found that other positive experiences with science during childhood, such as conducting science experiments at home, could influence primary teachers' science self-efficacy.

Mastery of science content also appears to have an influence on teaching self-efficacy. Preservice elementary teachers who had taken more college science classes were more likely to be self-efficacious when it came to teaching science (Bleicher, 2004; Bursal, 2010; Hechter, 2011). Even the number of science classes preservice elementary teachers completed in high school may influence their self-efficacy (Cantrell, Young, & Moore, 2003; Mulholland, Dorman, & Odgers, 2004). Teacher education and professional development programs designed to improve content knowledge have led to similar results. Elementary teachers who participated in professional development programs that emphasized understandings of science were subsequently more self-efficacious as science teachers and performed better on tests of content knowledge (Sandholtz & Ringstaff, 2011; Sinclair, Naizer, Ledbetter, 2011). Similarly, preservice elementary teachers who enrolled in methods classes designed to support understandings of earth science demonstrated improved conceptual understanding and had higher science teaching self-efficacy (Bleicher, 2007; Bleicher & Lindgren, 2005). Liang and Richardson (2009) found that prospective elementary teachers who engaged in their own inquiry-based research projects had greater science teaching self-efficacy gains than did peers not engaged in such a project.

Of course, mastery of pedagogical skills is also important in the development of science teaching self-efficacy. Preservice elementary teachers in Palmer's (2006a) mixed methods study reported that learning how to teach their subject matter functioned as a powerful source of science self-efficacy. Moreover, when Palmer (2006b) interviewed preservice teachers nine months after completing a science methods class, many indicated that participation in a subsequent teaching practicum had reinforced their self-efficacy.

As previously mentioned, teaching experience in itself has an unreliable influence on teaching self-efficacy. The type of support preservice teachers receive during early field experiences may moderate this influence. Experiences that provide teachers with content knowledge, teaching strategies, and an opportunity to apply both in an authentic setting can have a powerful influence on teachers' self-efficacy beliefs. Such experiences have been found to improve science teaching self-efficacy in both teacher education contexts (Mulholland, Dorman, & Odgers, 2004; Swars & Dooley, 2010) and intensive professional development programs (Lakshmanan, Heath, Perlmutter, & Elder, 2011; Lumpe et al., 2012). Brand and Wilkins (2007) found that, upon completion of a science methods class, preservice elementary teachers were most likely to identify mastery experiences in the form of content or pedagogical knowledge as sources of their improved self-efficacy.

Teachers have identified many forms of *vicarious experience* in their early teaching endeavors. In Palmer's (2006a) study of preservice elementary teachers in a methods course, many participants described the mastery experience of learning pedagogical skills in a methods course in a manner consistent also with cognitive self-modeling. That is, not only did participants add to their arsenal of teaching strategies, but they also "could see" (p. 247) themselves using these strategies in their own classrooms. Bandura (1997) argued that such vicarious experiences,

in which people envision themselves mastering a challenging task, can improve self-efficacy and future performance. Preservice elementary teachers reported higher self-efficacy following a science methods class in which they saw videos of master teachers, observed science teachers in their field experiences, and took classes in which the instructor modeled effective teaching practices (Bautista, 2011). In follow-up interviews, participants identified these vicarious experiences as more powerful sources of their self-efficacy than the feedback they received or the experiences they had planning and implementing lessons in their field placements. Primary teachers in Mansfield and Woods-McConney's (2012) qualitative study spoke of the importance of seeing others perform successfully in scientific endeavors, even if on science television programs. In studies by Cone (2009) and Palmer (2011), preservice teachers identified vicarious experiences in the form of observing peers or college instructors as important sources of their self-efficacy, particularly in the absence of authentic teaching experiences. Indeed, as Bandura (1997) noted, vicarious information may be particularly important when the task is relatively novel and individuals have had few opportunities to evaluate their own capabilities. Less is known about how vicarious experiences may influence the self-efficacy of veteran teachers.

In some cases, modeling, or a lack of it, may have a negative influence on efficacy perceptions. In Mulholland and Wallace's (2001) case study, an elementary teacher in Australia recalled few experiences in which she had seen others teach science at her preservice field placement. And once employed, she found that other teachers often shared their own doubts and misunderstandings about their science instruction. In this way, it is possible that the low science teaching self-efficacy of others may actually be contagious—teachers who arrive at schools without adequate support in scientific content and teaching strategies may become less confident

when surrounded by experienced teachers who are themselves less confident, and less competent, as science teachers.

Few researchers have explored *social persuasions* in the context of science teaching, but there is some indication that the messages teachers receive can serve as potent sources of their self-beliefs. Cone (2009) explored the self-efficacy of preservice teachers in a science methods course designed to provide them with mastery experiences, vicarious experiences, and social persuasions. The feedback teachers received following a simulated lesson was a powerful source for most teachers, and those who did not have opportunities to teach children rated such feedback as the most influential source of their self-efficacy. Similarly, Palmer (2011) found that inservice elementary teachers rated feedback from an outside observer as having the greatest impact on their science teaching self-efficacy following a professional development program that incorporated elements of all four hypothesized sources. In Mulholland and Wallace's (2001) case study, social persuasions – in this case, the apparent excitement and engagement of students during science lessons – provided a powerful source of self-efficacy for an elementary teacher as she transitioned from being a preservice to an inservice teacher. Given that success in teaching is largely dependent on the quality of social interaction between teacher and student, more research is needed to explore the implicit and explicit messages teachers receive from their students.

The relationship of *physiological and affective states* to teachers' beliefs about their ability to teach science is unclear. Preservice teachers who completed a science methods course with authentic teaching experiences were more self-efficacious, but were not significantly less anxious about science in general (Bursal, 2012). Few mentions of physiological and affective states have arisen in qualitative investigations of the sources of science teaching self-efficacy

(Mulholland & Wallace, 2001; Palmer, 2006a; Palmer, 2011). However, it is possible that, when asked to self-report, teachers underestimate the influence of these states because the influence tends to be ongoing rather than episodic. And although researchers tend to focus on the negative impact of physiological and affective states, positive states may also influence science teaching self-efficacy, such as the "joy" described by a participant in Mansfield and Woods-McConney's (2012) study when students "find out for themselves, especially for the first time" (p. 43).

Contextual factors. Teachers' self-efficacy is sensitive to the context in which they are teaching. In their seminal article, Tschannen-Moran, Woolfolk Hoy, and Hoy (1998) noted that teaching self-efficacy "has been defined as both context and subject-matter specific. A teacher may feel very competent in one area of study or when working with one kind of student and feel less able in other subjects or with different students" (p. 215). In general, characteristics of a classroom, such as class size, ability grouping, and grade level, influence perceptions of teaching self-efficacy (Raudenbush, Rowan, & Cheong, 1992; Ross, Cousins, & Gadalla, 1996; Ross, Cousins, Gadalla, & Hannay, 1999). Andersen, Dragsted, Evans, and Sørensen (2004) examined how the self-efficacy beliefs of preservice Danish elementary science teachers changed over the course of their first year of teaching. They found that these changes were positively correlated with the presence of environmental factors (e.g., small class sizes, science instructional materials, technological resources) that they believed would enhance their teaching. In follow up interviews, participants expressed concerns about the lack of instructional materials and time designated for science instruction but felt that support by other teachers was critical to their self-efficacy development. Lumpe, Haney, and Czerniak (2000) reported a moderate correlation between these context beliefs and the science teaching self-efficacy of K-12 teachers.

It is unclear what influence student background has on teachers' beliefs about their science teaching abilities. In one study, preservice elementary teachers tended to be self-efficacious with regard to teaching students of different genders, socioeconomic backgrounds, ethnicities, and language backgrounds. However, when interviewed after their initial field experiences, they minimized the importance of student demographics to their effectiveness as science teachers (Settlage, Southerland, Smith, & Ceglie, 2009; see Gay, this volume, for a possible explanation for this practice). On the other hand, experienced K-12 science teachers reported pedagogical discontentment when working with students who were different from them in some manner, such as students of different science backgrounds, different abilities, and English Language Learners (Southerland, Sowell, & Enderle, 2011). Moseley and Taylor (2011) also reported that middle and high school teachers in their sample, most of whom were White, were less confident in their ability to teach science when working in classrooms with larger numbers of African American, Latino, and American Indian students. However, Stipek (2012) found that, when other variables (i.e., perceived support from teachers and parents, socioeconomic status, grade-level performance) were held constant, elementary teachers' general self-efficacy was higher in classes with larger numbers of African American and Latino students. Clearly, the relationship between teachers' self-efficacy and students' background is complex and likely dependent on a number of variables. If one of the goals of teacher education is to produce teachers who are culturally responsive, more research is needed that addresses teachers' self-efficacy for teaching students of different backgrounds (Siwatu, 2011).

Implications for Theory and Practice

Meaning Systems: The Interaction Between Epistemic Beliefs and Self-Efficacy

How might these two important constructs interact with each other and function within a larger network of beliefs? Nearly three decades ago, Jean Piaget (1989) argued that people develop one of two different conceptions of the world. He hypothesized that individuals' conception of the world then filters one's sensory inputs. One conception of the world is described as a relatively static view of the world. The other view of the world is one that is dynamic and constantly being created and transformed. Although Dweck and her associates have developed a robust line of inquiry positing two worldviews framed around conceptions of ability as either fixed or incremental (Dweck & Leggett, 1988), we believe that epistemic beliefs can also be considered a type of meaning system in a similar manner to implicit theories of ability.

Molden and Dweck (2006) posit a meaning systems framework in which an individual variable is not the sole contributor to behavior. Rather, implicit beliefs bring together clusters of related beliefs and goals, which together exert their influence on behavior. We argue that epistemic beliefs function in a similar manner. Figure 1 illustrates this hypothesized model. First, epistemic beliefs can be conceptualized as individuals' beliefs about the static versus dynamic nature of scientific knowledge and knowing. For example, science can be seen either as a static collection of knowable absolute truths, or it can be seen as a dynamic and contextual body of knowledge.

Insert Figure 1 About Here

Second, when individuals hold these conceptions of science as either static or dynamic, they tend to orient their goals toward either performance goals (i.e., teaching science topics so that their students can demonstrate competence in science) or mastery goals (i.e., teaching science topics with the goal to help students understand the complexity of science; Bråten &

Strømsø, 2004, 2005; Chen & Pajares, 2010). And third, as in Dweck and Leggett's (1988) conception, self-efficacy serves as an important moderator of which types of behavior are ultimately manifested. For example, if teachers see science as mostly a collection of simple absolute truths, they may be more inclined to see their goal as getting their students to recall and demonstrate their scientific knowledge on tests. And if teachers are confident in their abilities to engage students and teach them these scientific truths (i.e., possess high science teaching self-efficacy), they are more likely to do an effective job at preparing students to perform well on these tests. Low teaching self-efficacy, however, is likely to result in ineffective teaching of the science canon.

On the other hand, if teachers see science mostly as a dynamic and evolving body of knowledge, they may be more likely to see their goal as providing students with opportunities to understand and appreciate the complexity of scientific concepts. Furthermore, if teachers believe that they are equipped with the necessary knowledge and skills to engage and teach students these dynamic scientific concepts, teachers are more apt to engage their students in more complex science activities that allow students to grapple with this complexity. However, if teachers lack the self-efficacy to engage students and teach them the dynamic and evolving nature of science, they are more likely to see their job mostly as depositing pieces of knowledge into students' minds.

This conception helps explain why teachers' beliefs about the simple nature of science translate into didactic practices, but beliefs about a complex nature of science do not necessarily translate into constructivist pedagogical practices. Science teachers' self-efficacy to engage and teach students to meaningfully grapple with the complexity of science moderates whether their

beliefs about the complexity of science actually get expressed. Further research, of course, is needed to test this model with science educators.

Implications for Science Education

Taking a meaning systems approach to epistemic beliefs and self-efficacy can shed light on the professional development of science teachers. As shown in Kang and Wallace's (2004) study, teachers who held sophisticated views about science did not often translate those beliefs into practices that reflected those beliefs. What seemed to be the limiting factor was teachers' belief that they could not teach in a way that reflected the complexity of science. As Kang and Wallace and other researchers have shown, teachers' lack of self-efficacy to teach the complexity of science was attributed to institutional structures such as the burden to teach to a test or the lack of resources provided to science teachers. Researchers also identified personal factors such as classroom management skills in explaining why teachers did not teach the complexity of science despite holding these sophisticated beliefs.

As Bandura (1997) argued, lack of resources, for example, does not in and of itself possess the "power" to prevent teachers from teaching a certain way. Rather, teachers' beliefs in their efficacy to engage and teach students effectively are informed by the context of the situation (e.g., how much institutional pressure I have to teach to a test, or how many resources I am given to teach my students). Therefore, teachers' self-efficacy for teaching science given their own individual context will likely influence teachers' implementation of curricula that either support or thwart the development of students' beliefs about the complexity of scientific knowledge, their appreciation for science, and ultimately their achievement in science.

Developing Science Teachers' Practices

It is critically important to develop teachers' conceptions about science and their self-efficacy for implementing curricula that help further students' evolving conceptions about science. For this reason, teacher educators are faced with a substantial challenge: How can teachers develop both the beliefs and the practices that reflect the complex work of actual science professionals? Many who have investigated the effectiveness of teacher education and professional development programs have done so with the apparent assumption that changing teachers' self-efficacy beliefs and their beliefs about the nature of science will lead to improvements in their instruction. Guskey (2002) challenged this notion, however, arguing that "significant change in teachers' attitudes and beliefs occurs primarily *after* [emphasis added] they gain evidence of improvements in student learning" (p. 383). He proposed that professional development influences teacher beliefs primarily when it provides teachers with the tools to succeed in a classroom, which in turn lead to enduring, adaptive beliefs (Guskey, 2002; Guskey & Yoon, 2009). Giving teachers the resources and training to improve their craft, and then providing personalized feedback of the effects of their teaching may be a more productive way to generate changes to teachers' practice *and* their beliefs about competence and the nature of science. We provide examples below.

First, although not in the science teaching literature, the work of Pianta and his colleagues is particularly illuminating because it illustrates a model of teacher change that can be applied across subject areas. These researchers have shown that teachers' beliefs about the importance of active teacher involvement in young children's development of language skills can be effectively changed by first changing their practices (Hamre et al., 2012; Pianta, Mashburn, Downer, Hamre, & Justice, 2008). In their model of teacher change, the researchers posited that their professional development intervention would directly influence teachers' beliefs and

knowledge about the importance of early and close teacher interactions with students in developing students' literacy. However, they also posited that their professional development course would provide teachers with the necessary skills to actually implement best practices involving close teacher-student interactions, and that these learned skills would change teachers' beliefs as well as their practices. Therefore, in this model, changing teachers' practices did not have to *first* pass through teachers' beliefs.

One intriguing aspect of the practice-focused professional development in the study by Pianta et al. (2008) is that teachers would film themselves implementing an instructional activity, and then send the film to a consultant. The consultant then edited the video to highlight 1 to 2 minute segments that focused on specific behaviors. These edited film segments were accompanied by written feedback from the consultant, which focused on specific aspects of the teachers' practice. Teachers then met online to discuss the feedback and to problem-solve. This strategy of having teachers watch edited segments of themselves may target teachers' self-efficacy and their beliefs about the importance of active involvement through the use of self-modeling and social persuasions (Bandura, 1997). Teachers who can see how specific changes in practice can result in corresponding student outcomes are much more likely to (a) be confident about their teaching capabilities *and* (b) understand the importance of enacting these practices.

Tan and Towndrow (2009) conducted a similar study in which they described the changes that one science teacher underwent as she used digital video recordings of herself to change her use of formative assessments in science. The authors noted that the science teacher was able to meaningfully change her assessment practices and her beliefs about the importance of listening to students only after she had seen the effects of her own actions on video and was able to collaborate with a researcher to design and implement modifications to her practice.

What these studies suggest is that teachers in general, and science teachers in particular, have a difficult time seeing their own actions and understanding the effects of those actions on students. By examining these actions and modifying them to better suit the needs of their students, teachers can develop corresponding changes in their beliefs.

This model of teacher change also informs the results of Waters-Adams (2006) mentioned earlier. As Waters-Adams noted, student-teachers need opportunities to enact their practices and observe their effects within a classroom. These experiences, supported through mentors or other colleagues, can then develop student-teachers' self-efficacy to enact rich science inquiry lessons.

Furthermore, if we employ the theoretical meaning systems model outlined in Figure 1, we can apply this conception of teacher change to the ways in which teachers teach the complexity of science. For example, Elena, a hypothetical high school chemistry teacher, holds a simplistic view that science really is a compilation of basic truths (i.e., she holds a belief in the "fixed" nature of science). She also feels constrained by the overwhelming focus on standardized tests and the logistical difficulty of providing students with hands-on activities in science (i.e., she has a low self-efficacy for implementing inquiry science practices). If, however, she were able to videotape herself implementing a more constructivist approach to a lesson (in collaboration with others, such as a mentor teacher or a researcher), Elena might witness firsthand that her students were more engaged with the material, and were beginning to develop a more nuanced view of science and how scientific knowledge is created. As Elena continues to change her *practice*, and witness the positive effects of these practices, she is more likely to develop a *belief* in her efficacy for teaching science in a constructivist manner. Just as

important, she is also more likely to develop beliefs about science that are more in line with how scientists think about knowledge and knowing.

This idea of changing beliefs by doing is not a new one. Over a century ago, William James (1899/1962), in his book *Talks to Teachers on Psychology: And to Students on Some of Life's Ideals*, declared:

> No reception without reaction, no impression without correlative expression, -- this is the great maxim which the teacher ought never to forget. An impression which simply flows in at the pupil's eyes or ears, and in no way modifies his active life, is an impression gone to waste. . . . Its motor consequences are what clinch it. (p. 17)

Thus, the chief purpose in science teachers' professional development must be to support teachers through a wide range of successful instructional experiences that involve the use of rich scientific inquiry. By supporting science teachers through the *doing* of teaching inquiry, teachers may come to *believe* more in the efficacy of their abilities to implement successful scientific inquiry lessons for students. But, just as important, by enacting the processes that actual scientists go through, science teachers' views about scientific knowledge and knowing may become more aligned with the views held by the majority of scientific professionals.

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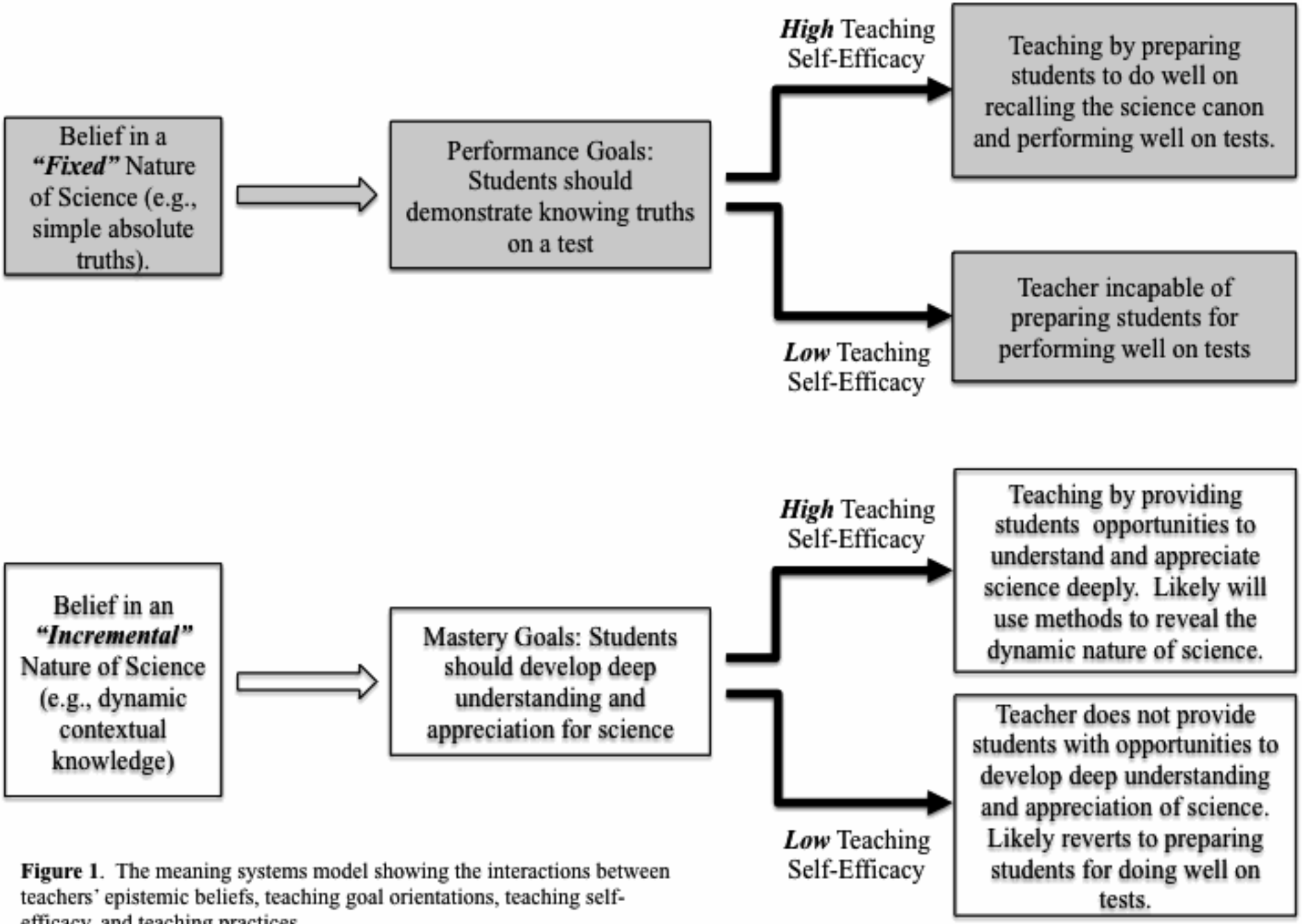

Figure 1. The meaning systems model showing the interactions between teachers' epistemic beliefs, teaching goal orientations, teaching self-efficacy, and teaching practices.