SCIENCE TEACHERS’ EPISTEMIC COGNITION IN INSTRUCTIONAL DECISION MAKING

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ABSTRACT

One understudied barrier to science education reform concerns teachers’ cognitive processes and how they relate to instructional decision-making. Epistemic cognition—teachers’ beliefs about knowledge and knowledge acquisition and goals for their students’ knowledge acquisition—could provide important insights into the choices science teachers make in the classroom and why they might and might not adopt different instructional practices. Previous research has found mixed results regarding the relationship between beliefs and practice. Uniquely, science teachers encounter epistemic beliefs from both science and education, with potential differences that may need to be negotiated. This study found significant differences between the two belief systems but failed to find differences between biology, chemistry, physics, and Earth science. Three profiles were identified that were significantly different on their epistemic beliefs in the natural sciences and the learning sciences. Those in the naïve profile (highest beliefs in certainty of knowledge, authority as source of knowledge, and attainability of truth) had significantly less self-efficacy than those in the sophisticated profile, which predicted lower frequency of investigative teaching practices and practices promoting an investigative culture. Those in the flexible profile (medium beliefs in certainty of knowledge, authority as source of knowledge, and attainability of truth) used practices promoting an investigative culture significantly less frequently than those in the sophisticated profile. The findings from this study add to the literature on epistemic cognition and its influences.
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CHAPTER 1
INTRODUCTION

“The good thing about science is that it’s true whether you believe in it or not.”
~Neil deGrasse Tyson

Overview

Science education in the United States has been suffering. Various reform efforts have been introduced over the years to improve it, however they have met limited success. Epistemic cognition, that is, teachers’ cognitive processes related to knowledge and knowledge acquisition (Chinn, Rinehart, & Buckland, 2014), could provide important insights into science teachers’ practices. Epistemic beliefs, beliefs about knowledge, are an important part of epistemic cognition. Previous research has demonstrated the importance and centrality of beliefs in human action. However, educational researchers have struggled to consistently find connections between teachers’ beliefs and their classroom practices. Additionally, science teachers are unique in their exposure to and training in two distinct domains with different and often conflicting epistemic norms, beliefs, and standards: education and science. Understanding how these potentially competing epistemic systems (Greene, 2016) interact will be a useful step in better understanding the relationship between beliefs and practice. Therefore, this study seeks to examine how science teachers’ epistemic beliefs about the science subject they teach and epistemic beliefs about the science of learning differ and how those differences influences their teaching practices.
To begin, I will provide an explanation of the current state of science education in the United States and some reform efforts that have been implemented to improve it. I will then explain epistemic cognition and epistemic beliefs and their role in predicting teacher practices. Following that, I will describe the different epistemic systems encountered by science teachers and how they might offer insight into the relationship between beliefs and practice within the epistemic cognitive process.

The Current State of Science Education

Science education in the United States has been under increased scrutiny in recent years as other countries have surpassed the U.S. in science achievement (National Research Council [NRC], 2012). Many reform efforts have been implemented to improve science education, however they have been met with limited success. Previous researchers found that the quality of high school science teaching continues to be poor and not aligned with research best-practices (e.g., Baniflower et al., 2013; Weiss et al., 2003). In the following section I will outline the current state of science education in the United States, as well as the research-support best practices for science teaching. I will then offer some potential impediments to teachers adopting successful teaching practices, which may be contributing to the current impoverished state of science teaching.

Using data from the National Survey of Science and Mathematics Education (NSSME), National Assessment of Educational Progress (NAEP), Teaching and Learning International Survey (TALIS), and Trends in International Mathematics and Science Study (TIMSS), as well as other empirical studies, the NAS (2015) conducted an extensive meta-analysis of teachers’ self-reported and observed teaching practices in K-
12 science and mathematics classrooms. As the current study focuses on secondary science teachers, I will highlight only the relevant information.

Overall, the study found a large gap between current practices and ideal practices as outlined in the *A Framework for K-12 Science Education* (NRC, 2012) and the Next Generation Science Standards (NGSS; NGSS Lead States, 2013). According to Baniflower et al.’s (2013) analysis of the 2012 National Survey of Science and Mathematics Education, 60% of science teachers report using “reform-oriented science teaching practices” (e.g., hands-on/lab activities), “require students to supply evidence in support of their claims,” and “have students represent and/or analyze data using tables, charts, or graphs” (2013). However, when asked about their typical classroom activities, teachers report using more traditional, teacher-centered practices such as the “teacher explaining a science idea to the whole class,” “whole class discussion,” and “students completing textbook/worksheet problems” (Baniflower et al., 2013).

Observational studies support the latter teacher-centered practices more so than the teachers’ self-reported use of reform-oriented practices. Weiss et al. (2003) observed two science classes at each of 31 nationally representative schools to rate the quality of overall instruction and individual practices. The researchers assigned ratings of one to five, with one representing “not at all reflective of best practice” and five representing “extremely reflective of best practice” (NAS, 2015). The authors rated only 15% of classes they observed as high quality utilizing student-centered teaching practices. Sixty-six percent of high school science lessons were rated as low quality, utilizing mostly teacher-centered teaching practices. The most common instructional practices used in
high school science classrooms were teachers explaining concepts to the whole class (i.e. lecture), small group work, and whole-class discussion.

The studies by the NAS (2015), Baniflower et al. (2013), and Weiss et al. (2003) provide a glimpse into the current state of secondary science education in the United States. It is largely teacher-centered, and consists of passive learning activities, which contribute to poor student outcomes (Lindblom-Ylännen, Trigwell, Nevgi, & Ashwin, 2006); there is little emphasis on authentic inquiry or the nature of science. Students develop fragmented scientific knowledge and lack opportunities to engage in authentic scientific inquiry, therefore resulting in the formation of partial or incorrect views of science and scientific knowledge (NAS, 2015).

Research-Supported Science Teaching Practices

What, then, is the ideal for science instruction? Weiss et al. (2003) defines high quality science lessons as those that engage students with key science concepts, enhance their understanding of said concepts, and encourage students to have meaningful interactions with the science content. Similarly, in their development of A Framework for K-12 Science Education the NRC used insights from various theoretical and empirical studies on science culture and teaching (NRC, 2012). They identified three key themes to form their basis of quality science teaching: 1) science learning involves both knowing and doing, 2) engaging in the practices of science is more productive for conceptual understanding than memorizing facts, 3) science learning experiences should be designed to scaffold knowledge and understanding over time (NAS, 2015). Specific suggested practices include asking questions; the development and proper use of models; planning and executing investigations; analyzing data and making interpretations; constructing
explanations; engaging in argumentation based on evidence; and gathering, evaluating, and communicating information (NAS, 2015). Unfortunately, the aforementioned studies demonstrate that these practices are rarely implemented, but why?

*Barriers to Practice Implementation*

Various impediments to innovative and research-supported practices have been studied, including lack of content knowledge and pedagogical content knowledge, lack of school or district support, and beliefs and values regarding teaching (Anderson, 1996). Anderson (2002) calls external features impediments and refers to internal features, such as necessary changes in beliefs and values, dilemmas. Few studies have explored the dilemma of how teachers’ beliefs and values impede change in instructional practice, however numerous authors have found it to be an essential feature of practice adoption (Anderson, 2002; Johnson, 2006; Crawford, 2007). While the current study does not explore changes in beliefs, these studies demonstrate the importance of considering teachers’ beliefs, specifically beliefs about their content area and beliefs about learning, in teacher practice.

The current gap between research and practice in secondary science education is large, as evidenced by the above studies. While there are various reasons for this, one important, yet understudied factor is teachers’ beliefs, specifically their beliefs about science and their beliefs about how students learn. Research on epistemic cognition and epistemic beliefs is an area that can shed additional light on this potential dilemma in the adoption of research supported best teaching practices.
Epistemic Cognition and Epistemic Beliefs

Before embarking on the importance of epistemic cognition and epistemic beliefs to teacher practice, it is important to note their differences as well as how they are related. I will then describe their importance in teacher practice, as well as the nature and importance of their domain-specificity.

Definition of and Relationship Between Terms

Research in epistemological matters has utilized many different terms for similar concepts. Earlier terms such as epistemic positions (Perry, 1970), reflective judgment (King & Kitchener, 1994), personal epistemology (Hofer & Pintrich, 1997), epistemological reflection (Baxter Magolda, 2004), and epistemological beliefs (e.g., Schommer, 1990), have given way to the now most commonly used terms, epistemic beliefs (e.g., Muis, 2007) and epistemic cognition (Kitchener, 2002; Greene, Azevedo, & Torney-Purta, 2008).

While the two terms are related, they are distinct and their distinctions are important for understanding their relationship to each other and their relationship to teacher practices. In fact, the two terms are often used interchangeably in the literature, making the distinction between them uncertain. More recent work in this area has called for a separation between the two terms as the conflation has probably contributed to the difficulties in studying the phenomenon and using it as a valid predictor of student and teacher outcomes (Sinatra, 2016). Epistemic beliefs refer to one’s beliefs about knowledge and knowing (Hofer & Pintrich, 1997). Epistemic cognition, on the other hand, is “an umbrella term encompassing all kinds of explicit and tacit cognitions related to epistemic or epistemological matters” (Chinn, Buckland, & Samarapungavan, 2011, p.
141). Put more succinctly, “epistemic beliefs describe the contents of cognition…whereas epistemic cognition describes a process” (Sinatra, 2016, p. 4). Thus, epistemic beliefs are a part of the cognitive process and should be studied as such.

Relationship to Teacher Practice

As noted by Sinatra (2016), most research has focused on teachers’ epistemic beliefs, rather than their epistemic cognitive processes. Possibly for this reason, studies have found mixed results when attempting to find connections between teachers’ epistemic beliefs and teaching practices. Some studies assert that there is a strong relationship between beliefs and practices (e.g., Tsai, 2002, 2006) while others assert that there is either no relationship (e.g., Kang, 2008; Kang & Wallace, 2005) or that the relationship is not simple and direct (Hodson, 1993). Despite inconsistent findings, the most current research contends that our models of epistemic cognition will be more predictive if we shift our focus to the components and mechanisms of the epistemic cognitive process, and move away from the conceptualization and study of static, dichotomous epistemic beliefs in isolation (Sinatra, 2016). Chinn and colleagues (Chinn et al., 2011; Chinn et al., 2014; Chinn & Rinehart, 2016) also advocate for the inclusion of additional content components of epistemic cognition, such as epistemic aims, “goals related to finding things out, understanding them, and forming beliefs” (Chinn et al., 2011, p. 146). This broadened, more inclusive approach to the study of epistemic cognition beyond simply dichotomous beliefs necessitates broader, more inclusive methods of inquiry (Chen & Barger, 2016; Sinatra, 2016).
Domain Specificity of Epistemic Cognition and Epistemic Beliefs

As mentioned above, most research into the domain specificity of epistemic cognition has utilized measures of epistemic beliefs. It is therefore difficult to draw conclusions about the domain-specificity of epistemic cognition itself. However, given that research has repeatedly shown that epistemic beliefs are domain-specific (e.g., Muis, Bendixen, & Haerle, 2006; Buehl & Alexander, 2006), and given that numerous authors describe epistemic beliefs as part of epistemic cognition (Chinn et al., 2011; Greene & Yu, 2016; Sinatra, 2016), one could reasonably suggest that epistemic cognition would also be domain-specific.

Despite earlier debates, there is now a general consensus that individuals hold beliefs that are both domain-general and domain-specific (Muis, Bendixen, & Haerle, 2006; Buehl & Alexander, 2006; Muis, Trevors, Duffy, Ranellucci, & Foy, 2015), with many even suggesting that epistemic beliefs (and cognition) may be topic or even task-specific (Barzilai & Weinstock, 2015; Strømsø & Bråten, 2010; Trautwein & Lüdtke, 2007). In general, this body of research has found that people tend to believe that knowledge in domains traditionally classified as “hard” or “well-defined” (e.g., life/physical science, math) are more certain, simple, derived from experts, and does not allow for opinion or interpretation, whereas people tend to believe that knowledge in domains traditionally classified as “soft” or “ill-defined” (e.g., humanities, social sciences such as education) is uncertain, complex, derived from examining multiple sources, and considers different opinions and the reliability of those opinions (Barzilai & Weinstock, 2015; Muis et al., 2015). The contrast between these two belief systems is amplified in the case of science teachers who must encounter and reconcile beliefs from the
“hard”/“well-defined” domain of science and the “soft”/“ill-defined” domain of education.

Science Teachers’ Epistemic Cognition and Epistemic Systems

As mentioned above, epistemic beliefs (and, likely epistemc cognition) vary by domain. In their teacher education programs, secondary science teachers are exposed to two distinct domains: that of their specific science subject (e.g., biology, chemistry, physics) and that of education, each representing a unique epistemic system. An epistemic system (e.g., institutions, organizations, academic disciplines) “endorse[s] particular epistemic norms (e.g., substantiating particular knowledge claims qua knowledge), as well as particular epistemic procedures or practices (e.g., the scientific method, meta-analysis, etc.)” that affects the behavior of members of the system (Greene, 2016, p. 5). In the current study, science teachers are members of the epistemic system of science as well as the epistemic system of education, each with its own unique and often conflicting epistemic norms, procedures, and practices that influence how the members act. In the example of juries’ understanding of legal reasoning, misalignment between the epistemic systems of the lay jury people and that of the legal system could result in problematic and incorrect verdicts (Weinstock, 2016). Similarly, in the case of science teachers, misalignment between the epistemic systems of science and education could result in problematic teaching practices. For the purposes of this study, I am defining alignment of epistemic systems (and their components, e.g., beliefs) as similar or complementary epistemic norms, procedures, and practices. I characterize misalignment as dissimilar or conflicting epistemic norms, procedures, and practices.
Given the epistemic systems and nature of epistemic beliefs inherent to their domains of study, science teachers are likely to have misaligned beliefs about the nature and learning sciences. There are likely to believe that the nature of knowledge in the natural sciences is objective, certain, derived from authority, and leaves little room for negotiation. Similarly, they are likely to believe that the nature of knowledge in the learning sciences is subjective, uncertain, derived from personal experience, and open to opinions. When teachers engage in the cognitive process of instructional decision making, these two contradictory belief systems are activated. The misalignment in this example would likely result in transmissionist, teacher-center teaching practices such as lecture and closed-ended inquiry. However, misalignment in the opposite direction (i.e., belief that knowledge in the natural sciences is subjective, uncertain, etc. and knowledge in the learning sciences is objective, certain, etc.) would likely result in constructivist, student-centered teaching practices such as large and small group discussions and open-ended inquiry. It is important to note here that the terms alignment and misalignment are not value-laden. As evidenced by the previous example, both epistemic systems exhibit misalignment but result in very different outcomes. Similarly, systems that are very aligned at either end of the spectrum (i.e., both systems objective/certain or subjective/uncertain) are not inherently good to bad either. While previous research has found that alignment on the constructivist end does result in more research-supported student-centered teaching practices (Tsai, 2002), more research into how the two epistemic systems align and interact could provide significant insight into science teachers’ epistemic cognition in instructional decision making. Moreover, Greene (2016)
explicitly calls for more research regarding the interaction between different epistemic systems.

Aims of the Study

Science education in the United States has struggled to implement research-based teaching practices. While many of these barriers to implementation are external (e.g., lack of support), many others are internal (e.g., beliefs and values about content and learning that are not aligned with the practices). It is the latter which this current study aims to address through the study of secondary science teachers’ epistemic cognition—that is the cognitive process of instructional decision making that involves the consideration of epistemic beliefs, epistemic aims, and learning beliefs. This study aims to clarify the relationship between epistemic beliefs and teaching practices in the epistemic cognition process. More specifically, this study asks how the beliefs formed through science teachers’ membership in two distinct epistemic systems align, and how that alignment influences their teaching practice.

Definition of Terms

The following is a list of key terms used throughout the dissertation:

- Teachers’ beliefs – “Attitudes about education – about schooling, teaching, learning, and students (Pajares, 1992, p. 316); “Conceptual systems which are functional or useful for explaining some domain of activity (Nespor, 1987, p. 326)
- Epistemic beliefs – Beliefs (or systems of beliefs) about knowledge and knowing (Hofer & Pintrich, 1997)
• Epistemic cognition – “An umbrella term encompassing all kinds of explicit and tacit cognitions related to epistemic or epistemological matters” (Chinn, Buckland, Samarapungavan, 2011, p. 141)

• Epistemic beliefs about the natural sciences – Beliefs about the nature of knowledge in the natural sciences

• Epistemic beliefs about the learning sciences – Beliefs about the nature of knowledge in the learning sciences

• Teacher self-efficacy – Beliefs about one’s teaching abilities

• Epistemic aims – Aims or goals related to achieving epistemic ends or products

• Learning beliefs – Beliefs about how students learn
CHAPTER 2
LITERATURE REVIEW

Overview

Many educational philosophers and researchers believe that beliefs are the best predictor of human action (Bandura, 1986; Dewey, 1933; Fenstermacher, 1979; Nespor, 1987; Pajares, 1992). Therefore, in the context of education, a better understanding of teachers’ beliefs is essential to improving teacher practice. While studies of teachers’ beliefs have covered various areas, one understudied area is that of epistemic beliefs, beliefs about knowledge and knowing. Epistemic beliefs are an essential part of teachers’ belief systems and have been associated with teaching practices, student perceptions of the classroom, and student achievement (Muis & Duffy, 2013; Muis & Foy, 2010; Tsai, 2002, 2006). Epistemic beliefs have been found to be domain-specific, thus putting science teachers in a particularly unique situation. Their pre-service training in education and their science domain exposes them to conflicting epistemic beliefs, as the domains of education and science hold beliefs about knowledge and knowing that differ and often conflict. Some research has been done specifically into the epistemic beliefs of science teachers, however, not in a way that considers their other beliefs systems and how they interact.

This review will begin by discussing a brief history of the research on teachers’ beliefs and why they are important. Then, I will discuss the literature on epistemic beliefs, a specific type of belief that teachers hold. I will discuss why this particular kind of belief is important, as well as newly contextualized ways of studying. This leads to a
discussion on the small body of literature on the epistemic beliefs of science teachers. Finally, I will conclude that, given the importance of teachers’ beliefs, and the inherent conundrum faced by science teachers, more research needs to be conducted in this area and with new methodologies that better capture the phenomenon.

Teachers’ Beliefs

There is common consensus that teachers’ beliefs are important and could be the key to understanding teacher effectiveness (Bandura, 1986; Dewey, 1933; Nespor, 1987; Fenstermacher, 1979; Pajares, 1992). However, these authors also agree that teachers’ beliefs are complex and difficult to study. This is supported by the conflicting findings many empirical studies have found regarding the relationship between beliefs and practice. In the section below, I will begin by reviewing the literature on teachers’ beliefs, explaining what they are, why they are important, and why they have been difficult to study. Following, I will highlight some of the studies showing either coherence or a lack of coherence between teachers’ beliefs and practices, as well as possible explanations for the lack of coherence and ways to improve them.

Defining Teachers’ Beliefs

Research on teacher beliefs dates back as far as 1953 (as cited in Fives & Buehl, 2012). In his seminal 1992 article, Pajares defines teachers’ beliefs as “teachers’ attitudes about education—about schooling, teaching, learning, and students” (p. 316). Nespor (1987) defines beliefs “not so much sets of propositions or statements as…conceptual systems which are functional or useful for explaining some domain of activity” (326). Through their coding of over 300 articles on teacher beliefs spanning several decades, Fives and Buehl (2012) state that teacher beliefs consist of beliefs about the self, context
or environment, content or knowledge, specific teaching practices, teaching approach, and students. Additionally, the authors describe five common characterizations of teacher beliefs. Beliefs are (a) implicit or explicit, (b) stable or dynamic, (c) context-specific or generalized, (d) related or not related to knowledge, and (e) individual or part of a system.

How researchers characterize beliefs has very important implications for the validity and generalizability of their findings. For example, some authors suggest that beliefs are implicit (e.g., Kagan, 1992; Kang & Wallace, 2005; Hashweh, 1996), while others suggest that they are explicit (e.g., Greene, Azevedo, & Torney-Purta, 2010; Dai & Cromley, 2014a; Muis, & Duffy, 2013). The implications are that if beliefs are implicit they cannot be studied or measured directly and must be inferred based on interview responses and/or observation, thus falling prey to the researcher’s subjectivity. Conversely, if beliefs are explicit, they are subject to social desirability bias, teachers’ inability to articulate their beliefs, and teachers’ lack of awareness about their own beliefs (Fives & Buehl, 2012).

Beliefs exist on a continuum ranging from stable to dynamic. Older beliefs tend to be more stable, while newly formed beliefs are the most likely to be dynamic (Pajares, 1992). Beliefs are both context-specific and general, an assertion supported in the epistemic belief literature (see section below on epistemic beliefs). Moreover, the demands of specific contexts likely activate certain beliefs (Fives & Buehl, 2008). Knowledge and beliefs are interwoven, although it has proven to be difficult to differentiate them empirically (Murphy & Alexander, 2004; Southerland, Sinatra, & Matthews, 2001). While an erroneous distinction, beliefs are generally regarded as
subjective claims or conceptions, while knowledge is described as having elements of
objectivity and truth (Pajares, 1992). Finally, beliefs are best conceptualized as part of a
complex system of beliefs, although few researchers have actually studied them this way
(notable exceptions: Bryan, 2003; Mansour, 2008).

The Importance of Teachers’ Beliefs

As discussed above, beliefs are important influencers of action, but how exactly?
Beliefs serve as filters, frames, and guides for action (Fives & Buehl, 2012). In teachers,
the filter applies to what instructional methods they retain, think are most appropriate,
and use, as well as what information they share with their students (pedagogy and
content). Framing occurs by helping teachers define the task or problem at hand. Beliefs
guide action by influencing (guiding) which actions teachers will take in a particular
situation. All three of these functions of beliefs highlight the connection to teacher
practice. However, historically this has not been easy to study.

The Difficulty in Studying Teachers’ Beliefs

Despite the growth in the body of research on teachers’ beliefs, few substantive
conclusions have been reached. Different authors have suggested different reasons for the
difficulties, such as the mysterious, clandestine qualities of beliefs (Pajares, 1992) and the
methodological difficulties in studying an ill-defined construct in an ill-structured domain
(Biglan, 1973; Nespor, 1987) Nespor calls education an “entangled domain” where
teachers encounter ill-structured problems. While there is no clear boundary between ill-
structured and well-structured problems, ill-structured problems fall towards one end of a
continuum according to how precisely defined the problem’s goal is and the procedures
for attaining that goal. Additionally, ill-structured problems like those encountered by
teachers require that individuals involved in the problem solving go beyond the immediately available information and access background knowledge or knowledge from other experiences that may apply (Simon, 1978, as cited in Nespor, 1987). Nespor contends that, when teachers enter the entangled domain of education and encounter an ill-structured problem, “many standard cognitive processing strategies – for example, schema-abstraction or analytical reduction – are no longer viable” (p. 325). The goals of the situation are unclear, the procedures for attaining the goal are similarly unclear, and the immediately available information does not provide the necessary knowledge for problem solving. It is for this reason that in these types of situations, teachers will resort to action based on their beliefs, rather than cognitive action that may have been employed in a well-structured domain or problem-solving area which they could more easily and readily draw on their cognitive processing resources.

*Inconsistent Findings*

Conversely, some studies find a lack of coherence and conclude that there is not a relationship between beliefs and practice (e.g., Kang & Wallace, 2005; Kang, 2008; Tobin, Tippins, & Gallard, 1994). Fives and Buehl (2016) instead suggest examining why there is a lack of coherence. Some suggested reasons for lack of coherence may be that the enacted beliefs were more central to the system (Pajares, 1992) or that contextual restraints, such as mandated curricula, may impede belief-practice coherence (Savasci-Acikalin, 2009). Many of the problems with studying teachers’ beliefs in general apply to the study of epistemic beliefs as well.
Epistemic Beliefs and Epistemic Cognition

Epistemic beliefs and epistemic cognition originate from the philosophical field of epistemology, the study of the nature and justification of knowledge (Hofer & Pintrich, 1997). As stated above, there is a general assertion that epistemic beliefs are important, for both students and teachers. However, they too have proven difficult to study for many of the reasons discussed above. In this section, I will describe the history of the study of epistemology (and epistemic beliefs) in educational contexts, followed by some of the problems with studying epistemic beliefs and how various researchers have attempted and are attempting to solve them.

Piaget (1950) first suggested the intersection between philosophy and psychology in his discussion of “genetic epistemology.” Since then, research into personal epistemology has taken three distinct paths: epistemic development (e.g., Perry, 1970; Kuhn 1991), epistemic cognition (e.g., Greene, Azevedo, Turney-Purta, 2008), and epistemic beliefs (e.g., Muis & Duffy, 2013).

The developmental paradigms of epistemology mostly began with Perry (1970) who built heavily off Piaget (1950) in his longitudinal study of men studying at Harvard. By analyzing the interviews, Perry and his colleagues developed a model of epistemological development that processed through four stages or categories: dualism, multiplism, relativism, and commitment within relativism (Perry, 1970). Belenky, Clinchy, Goldberger, and Tarule (1986) in their seminal piece, Women’s Ways of Knowing, expanded on Perry’s work by studying only women. Baxter Magolda’s work from the 1980s and 1990s built off both Perry and Belenky et al. By integrating college men and women in her longitudinal study, she developed a model focused more on the
nature of learner than of knowledge itself. Also building off the work of Perry (1970) and Dewey (1933) King and Kitchner (1994) further added to the developmental model of epistemology with their work on moral judgment and reasoning. Kuhn (1991) built on previous research with her work on argumentative thinking in everyday life situations.

Problems with the developmental approach such as the assumptions of unidimensionality of beliefs and fixed stages led Schommer (1990) to explore the notion that, rather than unidimensional, fixed stages, epistemological beliefs are multidimensional. Despite numerous theoretical and measurement issues with her instrument, Schommer makes an important contribution to the field in her use of quantitative studies and in linking epistemological position with student achievement.

Hofer and Pintrich (1997) synthesized and built off this work but diverged from it in important ways. Their seminal review article asserted that the study of epistemological beliefs should “be limited to individuals’ beliefs about the nature of knowledge and the process of knowing” (p. 117). Although they acknowledge the likely significant relationship between epistemic beliefs and beliefs about learning and ability, they feel such beliefs should be conceptualized and measured separately. Hofer and Pintrich (1997) proposed a four-dimensional model of epistemic beliefs; two dimensions measure the nature of knowledge (simplicity of knowledge, certainty of knowledge), and two measure of nature of knowing (source of knowledge, justification for knowing). Each of the four dimensions exists on a continuum. Simplicity of knowledge ranges from believing that knowledge is absolute to believing that knowledge is complex. Certainty of knowledge ranges from beliefs about knowledge as concrete and knowable to beliefs about knowledge as contextual and relative. Source of knowledge ranges from knowledge
originating from an external authority figure to knowledge being created by the knower. Justification for knowing ranges from dualist beliefs (e.g., right versus wrong) to multiplist beliefs (e.g., cultural relativism). When empirically testing this theory, Hofer (2000) found that simplicity of knowledge and certainty of knowledge loaded as a single factor, simple/certain knowledge. Additionally, a fourth factor was identified, attainability of truth, which had not been hypothesized previously.

An additional line of research in epistemic cognition emerged around the same time. The *epistemological resources* perspective views epistemic cognition as stable, trait-like beliefs that are activated by a specific context (Elby & Hammer, 2001). Epistemological resources emphasize the importance of fine-grained, context-specific investigations into epistemic beliefs. According to this framework, different contexts will trigger different epistemological resources. For example, a teacher might hold one set of epistemic beliefs regarding knowledge about the periodic table and a different set of epistemic beliefs regarding knowledge about evolution. The different contexts will activate different beliefs, which will likely trigger different goals and different actions in the classroom. This body of work contributes significantly to the field because, rather than viewing epistemic beliefs or cognitions as static beliefs or processes, epistemological resources views them as dynamic and fluid. This view is also consistent with the most current research on epistemic cognition which calls for a finer-grained approach to the study of this topic, including increased awareness to context (Chinn et al., 2011; Chinn et al., 2014; Sinatra, 2016).
Problems with Measuring Epistemic Beliefs

Many of the problems with studying epistemic beliefs stem from the problems of studying beliefs in general. There has been much debate about a few issues epistemic beliefs/cognition literature: 1) terms for describing or naming the phenomenon, 2) properly categorizing the phenomenon, 3) domain generality versus domain specificity, and 4) how to best measure the phenomenon in question.

Terms

In the literature, the terms have included personal epistemology, epistemology, reflective judgment, epistemic beliefs, and epistemic cognition. Epistemology is the study of the nature of knowing. Therefore, personal epistemology would be one’s personal study of the nature of knowing. That is why the field has moved away from these terms and towards the latter two which I will use going forward. Epistemic beliefs and epistemic cognition are found most prominently in the literature, with the current trend towards the latter, as many scholars feel the active cognitive process better captures the phenomenon in question. This being said, many researchers continue to study and use epistemic beliefs, many within the context of epistemic cognition (Buehl & Fives, 2016).

Properly categorizing the phenomenon

Scholars have included various constructs when describing or studying the phenomenon. Hofer and Pintrich (1997) summarized the different constructs included under the umbrella of epistemological beliefs up until that point including positions of intellectual and ethical development (Perry; dualism, multiplism, relativism) epistemological perspectives (Belenky et al.; silence, received knowledge, subjective knowledge, etc.), epistemological reflection (Baxter Magolda; absolute knowing,
transitional knowing, independent knowing, etc.), reflective judgment (pre-reflective thinking, quasi-reflective thinking, reflective thinking), and argumentative reasoning (Kuhn; absolutist, multiplist, evaluativist).

More recently, some scholars have called attention to the distinction between epistemic and ontic beliefs. Greene, Torney-Purta, and Azevedo (2010) specifically mention and address this distinction in the development of their measure. Epistemic beliefs refer to the nature of knowing, whereas ontic beliefs refer to the nature of knowledge. Some suggest that clarifying and teasing apart these two constructs will help us better study the construct in question (Sandoval, 2016).

*Domain generality versus domain specificity*

Most of the early research in this field assumed epistemic beliefs to be domain general (e.g., Perry, Kitchner, etc.). The surveys created to test them did not ask about or account for contextual differences. In Hofer and Pintrich’s 1997 review, they called attention to this area of future research and encouraged scholars to explore the domain-specificity of epistemic beliefs. Many researchers did and it is now generally agreed upon that epistemic beliefs are both domain-general and domain-specific (Buehl & Alexander, 2006; Muis, Bendixen, Haerle, 2006).

Buehl & Alexander (2006) proposed a model depicting the relationship between different levels of beliefs, mostly between domain-specific and domain-general beliefs. Their argument rests on the assumption that beliefs about knowledge reflect the nature of knowledge, that is, multidimensional, multilayer, and complex. They posit that “the knowledge individuals acquire and the experiences that give rise to that knowledge are influential in forming epistemological beliefs” (p. 31). As an extension, they discuss the
sociocultural influences on belief formation (e.g., teachers and classroom contexts). Just as some knowledge remains tacit until activated, they believe beliefs may also be tacit until activated and teachers play a key role in belief formation and appropriate belief activation (i.e., beliefs that fit the situation). Similarly, over time as there are quantitative and qualitative changes in knowledge, there are also quantitative and qualitative changes in beliefs about knowledge. This has been supported by numerous previous studies that epistemic beliefs become more advanced as one gets older and acquires more education (although not necessarily uniformly across domains). The authors highlight the somewhat obvious assertion that domain-specific epistemological beliefs do not arise if they are not specifically measured. While treating epistemic beliefs as both domain-general and domain-specific has helped the predictive validity of these measures a bit, more current research has called for research into epistemic beliefs to be context-specific, breaking down the domain- or subject-specific component even further (Sinatra, 2016).

Measurement issues

The field of research into epistemic beliefs began qualitatively with most of the early work consisting of interviews (Perry, 1970; Belenky et al., 1986; Baxter Magolda, 1992; King & Kitchener, 1994). Schommer (1990) developed the first quantitative measure of epistemic beliefs. Since then, numerous quantitative measures have been developed and used (e.g., Greene, Azevedo, Turney-Purta, 2010; Muis et al., 2015; Schraw, Bendixen, & Dunkle, 2002; Wood & Kardash, 2002), however, these instruments have proven to be problematic as DeBacker, Crowson, Beesley, Thoma, and Hestevold (2008) point out. Their two main concerns are 1) theoretical – the instruments try to combine items that are clearly epistemic (beliefs about the structure of knowledge)
and items that are more closely related to beliefs about learning; and 2) empirical – the studies found unstable factor structures and low reliability coefficients. They start with the most frequently cited measure in the literature, the Epistemological Beliefs Questionnaire (Schommer, 1990). Some studies using this scale (there are a few different versions of the scale used) found four factors, while others found three; more importantly, the factors were not identical. This is probably because, rather than putting the items into the exploratory factor analysis (EFA), Schommer recommends using the item subsets. Internal consistency statistics in these studies have also been low. Next, they analyzed the Epistemic Beliefs Inventory (Schraw et al., 2002) and the Epistemological Beliefs Survey (Wood & Kardash, 2002). The Epistemic Beliefs Inventory had inconsistent factor structures; some studies found the hypothesized five factors while others did not. The Epistemic Beliefs Inventory and the Epistemic Beliefs Survey had low internal consistency. The authors then conducted their own studies using these measures and ran confirmatory factor analyses (CFA). They found poor model fit and low subscale reliabilities with all of the instruments. The authors concluded by cautioning against simply using domain-specific items as these instruments have also not fared well. They suggest a greater theoretical grounding for the development of measures of epistemic beliefs.

Despite the well-known problems with these instruments, researchers continue to use them and cite the significant relationships between epistemic beliefs and various academic outcomes (e.g., Muis & Foy, 2010). Some suggestions for improving these problems include task and context-specific questions, interviews, observation, and looking at epistemic cognition as a process as opposed to static dichotomous beliefs. As I
will describe below, Chinn and colleagues (2011, 2014) specifically suggests that researchers have failed to find significant connections between epistemic beliefs and measures of reasoning and learning because they fail to consider the epistemic aims people adopt (or fail to adopt) in the situations or contexts being studied.

Connection to problems in studying beliefs in general

Both the teacher belief and the epistemic belief literature agree that some beliefs are more universal and generalizable, while others are more context and situation-specific. One issue the epistemic belief/cognition literature does not address is that of belief systems and how epistemic beliefs/cognitive process relate as part of a complex system, interacting with other beliefs and cognitive processes. Human beings are complex. Individual beliefs and cognitive processes rarely exist in an isolated bubble, yet research has continued to study them that way. While the model described below does not explicitly use the complex systems terminology, it is one of the only frameworks that discusses how different elements of epistemic cognition relate to each other and work together.

AIR Model of Epistemic Cognition

In 2011, Chinn, Buckland, and Samarapungavan wrote a paper drawing heavily on the philosophical background of epistemology. Epistemology began as a philosophical field of inquiry and Chinn et al. argue that educational researchers have strayed too far from its origins. By giving an in-depth examination of the philosophical roots of this construct and how they relate to educational settings, they developed the AIR Model of epistemic cognition (Chinn et al., 2014). “A” stands for aims and values, “I” stands for
ideals, and “R” stands for reliable processes (that is, reliable processes for achieving epistemic aims).

Aims and values

Epistemic aims refer to goals related to knowledge and knowledge acquisition (Chinn et al., 2011). Some specific epistemic aims include knowledge, true belief, avoiding false belief, minimally justified belief, understanding, and explanation (Chinn et al., 2011). In relating epistemic aims specifically to teachers, Buehl and Fives (2016) list three aims as most relevant: knowledge, true belief, and understanding. Knowledge is the most commonly discussed epistemic aim and refers to a collection of facts. Understanding is distinct from knowledge in that it involves making meaningful connections between pieces of information or facts (Kvanvig, 2003, as cited in Chinn et al., 2011). True beliefs refer to “beliefs that accurately represent particular aspects of the world (at least approximately) and that are supported by adequate reasons” (Chinn et al., 2011, p. 147).

Chinn et al. (2011) argue that including epistemic aims in the discussion of epistemic beliefs will help alleviate the problems epistemic beliefs have had with predictive validity. For example, students may believe that knowledge in a certain area is complex, uncertain, and justified by reason; however, they may fail to adopt epistemic aims (such as understanding the complex nature of knowledge in this area) that would cause the students’ beliefs to not be predictive of their outcome in the class.

Since the AIR model is still relatively new, very little empirical research has been conducted using it. Dai (2014) measured epistemic aims and source beliefs and their relationship with student outcomes on various chemistry topics. More than 350 students
enrolled in introductory chemistry read passages about various chemistry topics from an online source and then answered questions about their epistemic aims and source beliefs as they pertained to the passage they just read. Results showed three main epistemic beliefs – true belief, justified beliefs, and explanatory connections – that were specific to the topic about which they read. The author found significant relationships between learning outcomes on the topics and two epistemic aims – justified beliefs and explanatory connection. The more students aimed for justification, the lower they scored on the learning outcome measure; the more students aimed for explanatory connections, the higher they scored on the learning outcome measure. This shows that different aims are predictive of different outcomes, with some aims being more adaptive/supportive to learning than others.

Epistemic value refers to the values people place on their intended epistemic achievements. Epistemic achievements occur when one has attained an epistemic aim (e.g., knowledge, understanding, true belief). In certain fields, some types of knowledge seem to have greater value than others (e.g., theoretical knowledge in biology). Chinn et al. suggest two lines of research to explore epistemic value. First, they propose studying the value people place on different types of epistemic achievements. Second, they propose studying how people’s epistemic values relate to their learning process. For example, are students more likely to engage and better understand knowledge or processes that they value? Again, little empirical work has been done in this area.

Ideals

Epistemic ideals are “the criteria or standards that people use to evaluate whether they have achieved their epistemic ends” (Chinn et al., 2014, p. 434). This component of
the AIR model combines two constructs of epistemic beliefs that previous models have separated: the structure and justification of knowledge. Many times, the justification for knowledge is described in terms of its structure. For example, when describing why a particular scientific theory is sound, one might say it is good if it is simple and consistent with empirical data. The simplicity refers to the structure of knowledge and the consistency with empirical data refers to the justification for knowledge. The AIR model calls this category epistemic ideals (Chinn et al., 2014).

Reliable processes

Reliable processes are process by which epistemic products are achieved (Chinn et al., 2014). The reliability of the process depends upon its ability to meet one’s epistemic aims; a process is highly reliable if it is successful at achieving the epistemic aim and it is unreliable if it is unsuccessful in achieving the epistemic aim. For example, if a biology teacher has an epistemic aim for her students to develop models of scientific inquiry, lecture would probably be an unreliable process for achieving that goal, while guided laboratory experiments might be a more reliable process for achieving a model of scientific inquiry.

Epistemic Cognition in Teachers

Very little research has looked at the epistemic cognition of teachers and most empirical studies on the topic have been qualitative (e.g., Hancock & Gallard, 2004; Kang, 2008; Kang & Wallace, 2005; Lemberger, Hewson, & Park, 1999; Tsai, 2002, 2006). This is a strength of the body of research because the mostly semi-structured interviews and observations provide an in-depth look at the complex and poorly understood construct of beliefs. However, this is also a limitation in the body of research
because it makes it very difficult to draw conclusions about the relationship between beliefs and practice, as evidenced by the conflicting findings from these various studies. First I will describe an emerging model of teacher epistemic cognition that builds off of the AIR framework described above and integrates epistemic beliefs into the cognitive process. Then I will examine the literature on epistemic beliefs and cognition specifically in science teachers, highlighting some of the studies with conflicting findings.

**Model of Teacher Epistemic Cognition**

Buehl & Fives (2016) adapted Chinn et al.’s (2014) AIR model and applied it specifically to teachers. To start, they posited that epistemic cognition in teachers consists of two main tasks: teaching and learning. As teachers, they are engaged in the act of teaching others and (sometimes) simultaneously learning themselves. The task of teacher learning is not, however limited to the individual’s formal teacher education program and professional development experiences. Buehl & Fives also include informal learning in which teachers engage throughout their careers such as personal reading, discussions with colleagues, and personal reflections. Similarly, teaching is not exclusive to standing in a classroom full of students and delivering information or facilitating discussion. It also includes “a) planning to teach, b) instruction, c) assessment of student learning, d) classroom organization and management, e) developing relationships with and among students and parents, and f) attending to students’ socio-emotional and physical needs in the context of classroom life” (Buehl & Fives, 2016, p. 6). In learning, the focus is primarily on the self, while in teaching the focus is primarily on others. As teaching is the primary focus on this study, that task will be the assumed task from this point on in the discussion of this theoretical model.
After determining the task, one must determine which domain will be the area of focus. Buehl and Fives (2016) include six domains: subject matter, pedagogy, classroom management and organization, child development, context, and self/other. When examining epistemic cognition, one must first identify the task (teaching or learning) and the domain (see above) in which the cognitive processes are taking place. Then the teacher examines/identifies/sets their epistemic aims which Buehl and Fives limit to knowledge, understanding, and true belief. Once their aim is determined, the teacher then begins considering and evaluating the source, justification, certainty/stability, structure, and reliability of processes of the knowledge at hand. Buehl and Fives identify this phase as the cognition part, where the actual processes are taking place. Here they also make a notable departure or modification of Chinn et al.’s model. While Chinn et al. include epistemic vices and virtues under the I of ideals, Buehl and Fives group these, as well as prior knowledge, existing epistemic stances, and experiences of practice into Influences on Epistemic Cognition. This all then results in an “Epistemic Product,” which they call Epistemically Informed Praxis. They define Epistemically Informed Praxis as “the enactment of instructional decisions informed by the process of epistemic cognition engaged in to assist others in achieving specific epistemic aims (i.e., knowledge, understanding, and justified true belief)” (Buehl & Fives, 2016, p. 25). The complete model is presented in Figure 1.

Epistemic Beliefs and Cognition in Science Teachers

A small handful of studies have specifically examined science teachers’ epistemic beliefs and cognitive processes. Overall, this research has found inconclusive results in the alignment or coherence between teacher beliefs and practices. Some studies have
found that participants who hold more sophisticated epistemic beliefs enact more sophisticated and student-centered, constructivist teaching practices, while those who hold more naïve epistemic belief tend to use more teacher-centered, transmissionist teaching practices (Hashweh, 1996; Tsai, 2002, 2006; Beck, Czerniak, & Lumpe, 2000; Haney, Czerniak, & Lumpe, 1996). Other studies have not found conclusive connections.

Figure 1. Model of teachers’ epistemic cognition (Buehl & Fives, 2016)
Most of these studies have been qualitative and the few quantitative studies have very small sample sizes.

Hashweh (1996) conducted one of the few quantitative studies on science teachers’ epistemic beliefs. He gave a 3-part questionnaire consisting of critical incidents, direct questions about teaching strategies, and ratings of their strategy use and perceived importance of various teaching strategies to thirty-five teachers. The data supported the author’s hypotheses and found that teachers holding constructivist beliefs are more likely to detect student alternate conceptions, have more and better teaching strategies, use strategies more effective for inducing conceptual change in students, report more frequent use of these strategies, and highly value these strategies, all as compared to teachers holding more empiricist beliefs. These findings, however, were self-reported and did not include any classroom observations of the teachers.

Tsai (2002) undertook a qualitative study consisting of interviews of 37 secondary science teachers in Taiwan, seeking to understand the alignment between teachers’ beliefs about teaching science, beliefs about learning science, and beliefs about the nature of science. Each belief system was coded as either “traditional,” “process,” or “constructivist.” Tsai found that most teachers (approximately 50%) were traditional across the three beliefs, approximately 30% were process, and approximately 14% were constructivist.

Tsai (2002) also looked at the alignment between belief systems. Twenty-one teachers (60%) showed convergent beliefs across all three categories (Tsai called these “nested epistemologies”) however 15 of the 21 were traditional, 4 were process, and only 2 were constructivist. For the teachers who did not demonstrate consistent beliefs (16),
most of them (9) demonstrated alignment between teaching science and learning science. Nestedness was more common in more senior teachers, while the two teachers who showed constructivist alignment had 1-8 years of teaching experience.

In 2006, Tsai expanded on this work to include teacher practices. He examined science teachers’ scientific epistemological views (SEVs), their teaching beliefs, their teaching practices, their students’ SEVs, and their students’ perceptions of the science classroom. From a pool of 40 science teachers, the author chose 4 as participants in this study based on their diverse SEVs: one that scored high (highly constructivist; David), one that scored low (highly positivist; Andy), and two that scored in the middle (Betty and Cindy). All four taught 8th grade physical science in Taiwan. All teachers were interviewed and interviews were coded for SEVs. Teachers were observed and their actions were coded by time spent on activities. Students were given an instrument assessing their SEVs and a questionnaire assessing their perceptions of the science classroom. Using the five dimensions of SEVs (theory-laden exploration; invented and creative reality; changing and tentative feature; the role of social negotiation in the science community; cultural impacts), Tsai found that none of the teachers exhibited a purely positivist, mixed, or constructivist view across all five dimensions but varied on each. However, Andy was the most positivist, followed by Betty, Cindy, and David who was the most constructivist. Tsai found that teachers with more positivist-aligned SEVs had more positivist beliefs about teaching and more positivist teaching practices. Those with more constructivist-aligned SEVs had more constructivist beliefs about teaching and more constructivist teaching practices. Additionally, students taught by the more constructivist teachers had more constructivist perceptions of their science classroom.
This demonstrates the alignment I expect to see in my sample between beliefs about teaching science, beliefs about learning science, and teacher practices. Moreover, this study demonstrates the impact of teachers’ epistemic stances on their students, specifically their students’ perception of the classroom. (This is similar to Muis & Duffy [2013] in that the epistemic stances that inform teaching practices [explicitly or implicitly] can influence students’ epistemic beliefs, motivation, and learning strategies.)

A divergent line of research has found that beliefs and practices are not always neatly aligned (e.g., Kang & Wallace, 2005; Kang, 2008; Simmons et al., 1999; Tobin & McRobbie, 1996; Tobin, Tippins, & Gallard, 1994). Kang and Wallace (2005) used two aspects of epistemologies from studies by Belenky et al. (1986), Elby and Hammer (2001), and Kuhn and Weinstock (2002): the ontological aspect which pertains to the belief in one certain truth or uncertain multiple truths, and the relational aspect which refers to the relationship between the knower and the known, i.e., is the subject the receiver of knowledge, separated from the “sense-making” process or is the subject an active member of the meaning making process? They conducted semi-structured interviews with teachers to find out their goals for their students using lab activities. To assess epistemological beliefs, they used “critical incidents” (vignettes) to infer the participants’ epistemological beliefs, because people do not explicitly reflect on their epistemological beliefs (Hammer & Elby, 2002). This aligns with current theoretical work which calls for more in-situ research, including vignettes, to study epistemic beliefs (Sinatra, 2016). Results from the critical incidents indicated mismatch between beliefs and practice. The authors conclude this is because the critical incidents asked about close-ended lab activities so the epistemic beliefs that were activated were only in that
particular context. In their actual classroom in a different context, different epistemic beliefs are activated that may align more with practices. Their findings suggest that teachers with naïve epistemological views are more likely to have the goal of delivering information, viewing the students as passive recipients of knowledge. Their teaching practices include demonstrations and lecture. However, when teachers hold more sophisticated beliefs, the alignment between goals and practices becomes less clear. This is consistent with previous research that shows that sophisticated epistemic beliefs are rarely reflected in teaching practices (Kang & Wallace, 2005). Teachers with sophisticated epistemic beliefs may feel constrained by set curricula, and then can enact those beliefs sometimes but not others, as witnessed in one of their participants. Another participant held sophisticated epistemic beliefs about science but viewed “real science” as separate from “school science.”

Kang (2008), Mellado (1998), and Hancock and Gallard (1994) found similar results in pre-service teachers. Kang (2008) analyzed learning history essays written by 23 participants, as well as classroom observations, lesson plans, videos of their teaching, and self-video reflections, all of which were part of the science methods course assignments. Goals espoused included two main categories: usefulness of scientific knowledge for everyday life and developing scientific thinking skills for inquiry (analytical thinking, curiosity, logical thinking). Participants with more complex epistemic beliefs (science as evolving knowledge, knower seeks answers to their own questions) held goals about developing student knowledge and thinking skills for inquiry. Others with less sophisticated epistemic beliefs emphasized goals of the utility of scientific knowledge. Students in the former group “expected their students to be
scientists who can conduct scientific inquiry and hence, their teaching goals included thinking skills for inquiry” (p. 489). However, in all other participants, Kang found an overall disconnect between beliefs and practice.

This section highlights the inconsistent findings from studies attempting to link teachers’ epistemic beliefs and their teaching practices. While the suggested reasons for a lack of connection between beliefs and practice (e.g., social desirability, an inability to reflect on one’s epistemic beliefs, contextual constraints) apply to science teachers, science teachers also face an additional complication not faced by all other teachers: the conflicting epistemic traditions between their science domain and the domain of education to which they are exposed in their teacher education programs.

Domain Differences

Numerous studies have described the differences between different domains of academic study. Many of the initial studies classify disciplines as hard versus soft (e.g., Biglan, 1973) or well-defined versus ill-defined (Greene, Azevedo, Torney-Purta, 2008). Much of the research on epistemic cognition looking to measure domain differences has found that people tend to view knowledge in hard, well-defined domains as certain and absolutist and knowledge in soft, ill-defined domains as uncertain and multiplist (to use the developmental epistemic terminology of Kuhn and colleagues) (Muis et al., 2015; Brazilai & Weinstock, 2015). In this section I will describe the distinctions between the disciplines traditionally labeled “hard/well-defined” and “soft/ill-defined,” using examples of science as the former and education as the latter. Following that, I will describe two empirical studies that examined domain differences in epistemic beliefs.
Hard Versus Soft Disciplines

Biglan (1973) aimed to determine how faculty at two different types of colleges (one large, public in the Midwest; one small, private in the Northwest) characterized different academic disciplines. He hypothesized that disciplines would differ along at least two dimensions: paradigmatic v. non-paradigmatic and practical v. non-practical. One hundred and sixty-eight faculty from the large university and 70 from the small liberal arts college participated in the study. They were given index cards with different academic disciplines on them and asked to group them into categories. No criteria were given for similarities and there was no limit on the number of categories they could create. They were then given six dichotomous variables on which to rate each of the categories they made. The author analyzed the results using multidimensional scaling and found four dimensions: pure v. applied, hard v. soft, living v. non-living systems, and creative v. liberal arts. The fourth dimension was dismissed as it was only found in the liberal arts college. Biglan concluded that these findings are aligned with Thomas Kuhn’s discussion of paradigmatic v. non-paradigmatic disciplines, as more established sciences such as biology and chemistry fell into the paradigmatic (“hard”) end of the dimension, whereas education and the social sciences fell into the non-paradigmatic (“soft”) end.

There were some methodological issues with this study. To start, the two samples were given different disciplines to sort and different quantities. This could explain why the liberal arts sample found a creative v. liberal arts dimension and the university sample did not. Standardizing the quantity and quality of the disciplines to be sorted would have provided greater support for the dimensions that they found.
More recently, van Gigch (2002a, 2002b) looked at the epistemological differences inherent in the hard sciences (e.g., physics) versus the social sciences. The first part (2002a) focuses on physics as an example of a “hard” domain or an “exact” science beginning with its history. Initially, science (and physics) was restricted to the observable. Einstein was revolutionary in his assertion that we can make theories about things we predict to be true, even if we cannot observe them. Then, later physicists devised experiments to test these theories. That is how they discovered atoms and subatomic particles. When the wave versus particle debate came to be, Heisenberg’s uncertainty principle and Bohr's complementarity principle introduced the idea of uncertainty and imprecision into physics. van Gigch (2002a) summarizes two divergent trends in physics: complexity versus simplicity and precision versus imprecision. As systems become more complex our measurements/observations about them become less precise. As physics becomes more about embracing imprecision, social sciences are trying to become more precise and more certain. “The debate between the ‘exact’ and ‘inexact’ sciences continues” (p. 209).

In Part II of van Gigch’s description of epistemology in the sciences (2002b), the author discusses the social sciences. The author makes the distinction between the traditional social sciences (psychology, sociology, anthropology) and the “‘new” social sciences” (science of complexity, constructivist theories, sciences of the artificial, etc.). Additionally, and notably, he classifies education as a constructivist domain. He states that constructivists argue that old methods of reasoning and scientific investigation that were derived from positivism cannot and should not be applied to complex social systems such as human relationships, cognition, etc. He argues that observations cannot exist
without the observer so therefore objectivity is a myth. However, problems exist in measuring a complex phenomenon because strict constructivists believe that any model is a simplification and destroys the complexity of the system. This makes it almost impossible to study any complex system from a purely constructivist perspective. Our best models can only approximate what is actually going on in a complex human system.

**Domain Differences in Epistemic Beliefs**

Muis et al. (2016) sought to test the Theory of Integrated Domains in Epistemology (TIDE) framework, integrating the developmental (absolutist, multiplist, evaluativist) and multidimensional (simplicity, certainty, source, justification) perspectives on epistemic beliefs. Specifically, they wanted to determine if students’ epistemic beliefs were different in psychology, math, and general knowledge, if/how the beliefs are related, and how students express their beliefs across educational level and domain. Participants were 34 students from secondary, college, undergraduate, and graduate school, mostly from the social sciences. They all filled out three versions of the Discipline-Focused Epistemological Beliefs Questionnaire (Hofer, 2000), one for each of the domains, and then did a cognitive interview which was coded along the developmental and multidimensional perspectives. Overall, students’ math knowledge was the least constructivist and they were mostly multiplists on psychology and general knowledge. Interviews found that students viewed knowledge along the developmental framework with little reference to the multidimensionality. This contradicts other studies which have found support for the multidimensional framework in cognitive interviews. Despite limited experience in psychology, students were likely to be multiplists, even though they also had limited experience in math and were absolutists in that domain. The classroom
context was particularly salient in participants explaining their beliefs across domains and supports the TIDE framework of the social construction of beliefs. Students frequently referenced the type of instruction that varied by domain (more lecture, memorization, recitation in math; more discussion, debate in psychology). Additionally, this study supports previous research that epistemic beliefs vary as a function of life and educational experience.

In a study by Brazilai and Weinstock (2015), the authors tested a new measure of epistemic cognition, called the Epistemic Thinking Assessment (ETA), based on Kuhn et al.’s developmental perspective. The ETA presents two conflicting accounts of scenarios from two different domains (mutated frogs from biology, Livian War from history) and asks participants if it is possible to know which source is correct. Their approach emphasizes the metacognitive components of epistemic thinking (e.g., “Can one know for certain which account is right? How should one evaluate competing accounts?”, p.144) as opposed to measuring specific knowledge claims (e.g., Which account is right?). Items were designed to measure absolutist, multiplist, and evaluativist perspectives, as well as sub-scales measuring certainty, source, nature/structure of knowledge, and justification. The authors conducted four rounds of cognitive interviews before administering the pilot study to 272 participants, and then the large-scale study to 373 respondents, all adult students at a Hebrew-speaking university. The two-level model of the CFA yielded superior results in both cases supporting the subscales (certainty, source/justification; other subscales did not load on the FA so were omitted from the CFA). Correlations suggested that “views regarding the source and justification of knowledge tend to be more stable than views regarding the certainty of knowledge” (p. 152). ANOVAs
revealed highly significant main effects for epistemic perspective and scenario. Absolutism was most highly endorsed, followed by multiplism, then evaluativism. Absolutism was higher in the biology scenario than the history scenario and multiplism was higher in the history scenario. Evaluativism was not different between the two scenarios. The authors conclude that their findings support the multidimensional nature of epistemic thinking and the inclusion of the developmental perspective and the multidimensional perspective. They also conclude that there is less certainty in the domain of history than in biology.

This research supports the distinctions between the epistemologies of hard and soft sciences and domain differences in epistemic beliefs. Given the increased calls for contextual consideration when studying epistemic cognition, it becomes essential that researchers consider the various belief systems to which pre-service teachers are exposed during their training, which may contribute to their belief formation and activation as classroom teachers. This is particularly salient for science teachers who, in their pre-service training, are steeped in the epistemic cultures (Knorr-Cetina, 1999) of education, a social science characterized by constructivism and multiplism, and their science domain, a hard science characterized by positivism/post-positivism and absolutism.

Future Directions

Given the inherent conundrum faced by science teachers in their exposure to potentially conflicting epistemic systems and beliefs, they have the challenge of integrating two belief systems with contradictory assumptions. It is essential that future research examine the interplay between science teachers’ epistemic beliefs about science and their epistemic beliefs about learning, as well as how these beliefs align and the
impact that alignment has on their teaching practices. Additionally, previous research has shown that various factors contribute to variation in epistemic beliefs including previous research experience (Samarapungavan, Westby, & Bodner, 2006), level of education (Schommer, 1990), and years of teaching experience (Tsai, 2006), as well as hypothesized factors such as professional development experience, area of certification, and type of certification.

Moreover, the most recent research on epistemic cognition calls for both a broader conceptualization of epistemic cognition and a finer-grained analysis of the process (Chinn et al. 2011, 2014). For this reason, it will also be important to consider instructional decision-making as an epistemic process that involves the consideration of epistemic beliefs, aims, as well as other related non-epistemic beliefs and aims such as learning and ability beliefs.

*Other Factors Affecting the Relationship Between Beliefs and Practice*

As mentioned above, previous research has suggested that the lack of conclusive findings linking teachers’ beliefs and practices suggests that the relationship might not be direct. Various factors such as ability beliefs, and epistemic aims, ideals, and processes could mediate and/or moderate an indirect relationship between beliefs and practice. As I have already discussed the latter, the following sections will discuss teachers’ ability beliefs and their connection to epistemic cognition and teachers.

*Implicit theories of intelligence (ITI)*

ITI are conceptually different from traditional, historical conceptions of intelligence. Historically, theories of intelligence were predominantly conceptualized and measured explicitly; psychologists and social scientists would test individuals’ abilities to
complete performance tasks or measures meant to gauge intelligence. Examples of explicit theories are numerous and include Spearman’s two-factor theory and Piaget’s theory of equilibration (for a more detailed list see Sternberg, 1985). Conceptualizing intelligence in this way, however, has been problematic because psychologists have differing views on what intelligence really is. Implicit theories, however, do not derive from psychologists’ constructions of task performance. Instead, implicit theories are conceptualized as individuals’ own thoughts and explanations of how they understand intelligence. For example, early studies in implicit theories of intelligence asked experts what they thought intelligence was. Rather than being constructed in the way explicit theories of intelligence have been, implicit theories are uncovered as they exist in the minds of participants (Sternberg, 1985). According to the work of Carol Dweck and colleagues, there are two self-theories to which individuals adhere. The first, entity theory, states that one’s personal abilities are fixed and unchanging. The second, incremental theory, states that ability is fluid and can change over time. Most of this research has been conducted on students, however, the implications for teachers are clear and will be explained further.

Dweck, Chiu, and Hong (1995) documented students’ differential ability judgments based on whether they hold entity versus incremental beliefs. For example, Hong and Dweck (1992) and Zhao and Dweck (1994) measured participants’ theories of intelligence and subsequently examined their responses to failure—either hypothetical or actual (as cited in Dweck et al., 1995). They found that despite ability, entity theorists tended to blame setbacks on their own level of intelligence, whereas incremental theorists tended to implicate behavioral factors that could have led to failure, such as level of effort
or strategies employed. These self-judgments, in turn, have been linked to either positive or negative reactions to achievement challenges. Whereas entity theorists are discouraged by failure as it purportedly reflects their fixed intelligence levels, incremental theorists may increase effort or modify learning strategies in order to improve their achievement as intelligence is treated as malleable (Hong, Chiu, Dweck, Lin, & Wan, 1999).

**ITI and teachers.** Research on ITI has important implications for teachers. Students’ beliefs about intelligence impacted their attributions of success and failure, future learning strategies, and motivation. Similarly, teachers’ beliefs about intelligence could impact both their own attributions of success and failure as a teacher and, perhaps more importantly, could impact their attributions of their students’ successes and failures, influence what learning strategies they use with a student, and their overall motivation to help a student.

**ITI and epistemic beliefs/cognition.** Little work has focused on ITI and epistemic beliefs/cognition. However, one study by Bråten and Strømsø (2005) used Schommer’s Epistemological Questionnaire (SEQ; 1990) and Dweck’s Theories of Intelligence Scale (TIS; 1999) to measure the relationship between the two constructs and self-regulated learning strategies in first year education and business administration students (the U.S. equivalent of college freshmen). They used an item-level factor analysis of the SEQ in accordance with standard factor analytic procedures and found a 16-factor structure. By examining the scree plot and the eigenvalues, they forced a four-factor structure and named the factors 1) speed of knowledge acquisition, 2) certainty of knowledge, 3) knowledge construction and modification, and 4) control of knowledge acquisition. Factors 1, 2, and 4 aligned with Schommer’s (1990) findings and factor 3 aligned with
findings from a previous study by Wood and Kardash (2002). Bråten & Strømsø found low correlations between the four factors and the theories of intelligence, with the only significant correlation between control of knowledge acquisition positively correlated with entity beliefs and negatively correlated with incremental beliefs. These results indicate that epistemological beliefs (as measured by the SEQ) are separate and distinct from ITI and have a moderate relationship.

*Self-Efficacy Beliefs*

Self-efficacy beliefs refer to one’s beliefs about their ability to do something. Self-efficacy beliefs come from four main sources: mastery experience, vicarious experience, social persuasion, and affective states. Mastery experiences refer to experiences where the teacher has done really well at something (e.g., delivering a lesson or helping an individual student). Vicarious experiences are when they have seen or experience someone else doing something well (e.g., observing another teacher deliver a new teaching strategy effectively). Social persuasion refers to encouragement (or discouragement) from people or society around the teacher. Affective states refer to experience that have a high emotional quality to them (Tschannen-Moran & Woolfolk Hoy, 2001).

*Self-efficacy in teachers.* Teachers’ self-efficacy has been shown to be an important indicator in various student outcomes (achievement, motivation, efficacy), as well as related to teachers’ classroom practices (Tschannen-Moran & Woolfolk Hoy, 2001). Efficacy affects the effort teachers put into their teaching and the goals they set for themselves and for their students. Teachers with high self-efficacy are more organized, plan better, are more open to new ideas and are more willing to experiment with new
teaching methods (Tschannen-Moran & Woolfolk Hoy, 2001). Self-efficacy could also be an important mediator to explain some of the variation and lack of alignment between teachers’ beliefs and their teaching practices. For example, a teacher might hold an epistemic belief about the complexity of knowledge in science and believe that learning should include interactive inquiry-based experiences, however they have very low efficacy for their ability to effectively implement inquiry-based experiences. This would result in a misalignment between belief and practice and that would be unexplainable without the presence of efficacy. I was not able to find any published research connecting self-efficacy and epistemic cognition.

Conclusion

In conclusion, teachers’ beliefs, more specifically their epistemic beliefs, are important to better understand as they are predictors of their teaching practices. However, given the complex nature of beliefs combined with the complex environments in which they function, epistemic beliefs have historically been difficult to study and have yielded mixed results in terms of their connection to student and teacher outcomes. Science teachers face a particularly unique challenge in their training in two distinct epistemological traditions of science and education resulting in two potentially conflicting epistemic belief systems. The interplay between the two systems and its impact on their science teaching practices must be better understood in order to improve science teaching and education as a whole.
CHAPTER 3

METHODS

Overview

This study investigated the epistemic cognition of science teachers’ instructional decision making, utilizing measures of epistemic beliefs about the natural sciences and epistemic beliefs about the science of learning as predictors of teachers’ actions. Specific research questions include:

1. (a) Do secondary science teachers’ epistemic beliefs about science differ from their epistemic beliefs about how students learn?

1. (b) Do secondary science teachers’ epistemic beliefs about science and how students learn differ by discipline?

2. (a) How does the level of alignment between secondary science teachers’ epistemic beliefs about science and their epistemic beliefs about how students learn influence their science teaching practices?

2. (b) What role do epistemic aims and self-efficacy play in the relationship between secondary science teachers’ alignment in belief systems and science teaching practices?

In the following section I will describe the pilot study that led to the development of the final instrument, participants, recruitment strategies, measures and data analysis.
Pilot Study

A pilot study was conducted prior to the main study in order to test certain measures and obtain feedback on the overall survey structure, length, and format.

Participants

Pilot study participants were 36 pre-service middle or secondary science teachers from the United States. Participants received information about the study and were asked to sign an informed consent form. Participants received the survey via an online link. Five pre-service teachers were selected to participate in cognitive interviews, taking the survey online in front of the researcher and conducting think-alouds as they answered the survey.

Measures

The pilot study consisted of demographic and background questions, epistemic beliefs in the natural sciences, epistemic beliefs in the learning sciences, two different measures of epistemic aims, the vignettes, and a few questions about their experience taking the survey. (For full descriptions of the measures, see below.) The pilot study tested two measures of epistemic aims, one developed for the purposes of this study that included both epistemic and non-epistemic aims, and the other developed by Dai (2014).

Results

Dependent $t$-tests showed significant differences between pre-service teachers’ epistemic beliefs about the natural sciences and the learning sciences on the sub-con structs of certainty ($t(15) = 6.17, p < .001, d = 1.55$), personal justification ($t(15) = -4.93, p < .001, d = -1.33$), and source: authority ($t(15) = 2.70, p < .001, d = .69$), but not on attainment of truth ($t(15) = .79, p = .44, d = .19$). Both the newly developed and the
Dai (2014) epistemic aim scales had good reliability ($\alpha = .97$ and .86, respectively). I chose to retain the scale that I created for this study because 1) participants who took part in the cognitive interviews preferred the 5-point scale in these items to the 100-point scale in the Dai items, and 2) the Dai scale was developed prior to Chinn et al., 2014 which elaborated and expanded on the concept of epistemic aims, thus I was able to incorporate the most recent literature on the topic into the newly developed scale. Thirty-one percent of participants thought that the study thought it took “too long” or “a little too long” to complete. This study contained only a portion of the measures that would be on the main study, therefore efforts were made to shorten measures when possible.

*Modifications*

One modification that was made to shorten the survey was to eliminate the non-epistemic aims from the epistemic aims measure. I also modified some of the language in the Epistemic Beliefs – Learning subset of items to make the item meanings clearer based on feedback from the cognitive interviews (e.g., “In student learning, most problems have only one right answer.” was changed to “Most problems regarding how students learn have only one right answer.”).

*Main Study*

After making modifications to the survey based on the pilot study and cognitive interviews, I launched the full online survey, distributing it through various channels to middle and high school science teachers. The following sections will describe the participants, recruitment methods, measures, and analyses.
Participants

Participants consisted of 524 secondary (middle and high school) science teachers in the United States. Full sample demographics are below in Table 1.

Table 1

<table>
<thead>
<tr>
<th>Participant demographic data</th>
<th>Frequency</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Race</strong></td>
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<td></td>
</tr>
<tr>
<td>White/Caucasian</td>
<td>389</td>
<td>74.20</td>
</tr>
<tr>
<td>Black/African-American</td>
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<tr>
<td>Multiracial</td>
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<td>5.90</td>
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<tr>
<td>Hispanic/Latino</td>
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<td>5.30</td>
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<td>Asian/Asian-American</td>
<td>25</td>
<td>4.80</td>
</tr>
<tr>
<td>American Indian or Native</td>
<td>5</td>
<td>1.00</td>
</tr>
<tr>
<td>Alaskan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
<td>.20</td>
</tr>
<tr>
<td><strong>Sex</strong></td>
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<td></td>
</tr>
<tr>
<td>Male</td>
<td>268</td>
<td>51.80</td>
</tr>
<tr>
<td>Female</td>
<td>248</td>
<td>48.00</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
<td>.20</td>
</tr>
<tr>
<td><strong>Primary Subject Area Taught</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biology</td>
<td>219</td>
<td>41.80</td>
</tr>
<tr>
<td>Earth science</td>
<td>143</td>
<td>27.30</td>
</tr>
<tr>
<td>Physics</td>
<td>83</td>
<td>15.80</td>
</tr>
<tr>
<td>Chemistry</td>
<td>79</td>
<td>15.10</td>
</tr>
<tr>
<td><strong>Years Teaching</strong></td>
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<td></td>
</tr>
<tr>
<td>Not yet taught full-time</td>
<td>6</td>
<td>1.1</td>
</tr>
<tr>
<td>First year</td>
<td>40</td>
<td>7.6</td>
</tr>
<tr>
<td>1-2 years</td>
<td>87</td>
<td>16.6</td>
</tr>
<tr>
<td>3-5 years</td>
<td>179</td>
<td>34.2</td>
</tr>
<tr>
<td>6-10 years</td>
<td>113</td>
<td>21.6</td>
</tr>
<tr>
<td>11-15 years</td>
<td>39</td>
<td>7.5</td>
</tr>
<tr>
<td>16+ years</td>
<td>59</td>
<td>11.3</td>
</tr>
<tr>
<td><strong>Age</strong></td>
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<td>36.66</td>
</tr>
<tr>
<td><strong>Geographic Region</strong></td>
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<td></td>
</tr>
<tr>
<td>Northeast</td>
<td>132</td>
<td>26.7</td>
</tr>
<tr>
<td>Midwest</td>
<td>107</td>
<td>20.4</td>
</tr>
<tr>
<td>South</td>
<td>164</td>
<td>33.1</td>
</tr>
<tr>
<td>West</td>
<td>92</td>
<td>18.6</td>
</tr>
</tbody>
</table>
Recruitment

Teachers were recruited in the following ways:

1) Members from various professional organizations for science teachers including the American Association of Chemistry Teachers (AACT), the National Association for Research in Science Teaching (NARST), the American Association of Physics Teachers (AAPT), and the National Science Teacher Association (NSTA) sent emails on my behalf to member listservs and posted a link to my survey on their social media outlets. Members received an email with a link to the online survey asking them to complete it, followed by a follow-up email approximately one week later.

2) Through another research project on which I am currently working, I have access to a list of teachers in the Philadelphia School District. From this list, I emailed the survey link to the secondary science teachers asking them to participate. I sent a follow-up email one week later.

3) I posted messages asking for survey respondents on science teaching-related LinkedIn professional groups. Follow-up messages were posted on week later.

4) I posted my survey on Twitter utilizing hashtags popular with science teachers and education researchers such as #scienceteachers, #scienceed, #edchat, and #edresearch.

5) I utilized my personal network of education researchers, teachers, school and school district administrators, as well as parents of middle and high school-age children, asking them to forward the survey along to any middle or high school science teachers they knew.
6) Finally, a portion of the sample was recruited through Amazon’s mechanical Turk (mTurk), a crowdsourcing platform of online workers who complete surveys. mTurk participants received five dollars through the mTurk website upon completing the survey. Other respondents were offered the five dollars in the form of an online gift card after completing the survey.

**Procedures**

Prior to participant recruitment, human subjects approval was obtained from Temple University’s Institutional Review Board (protocol # 23942). Participants received information about the study and were asked to indicate consent at the end of the online informed consent form. Participants received the survey via an online link through Qualtrics.

**Measures**

Participants completed a questionnaire consisting of demographic questions, items measuring epistemic beliefs about science, epistemic beliefs about the science of learning, science teaching self-efficacy, beliefs about their students’ learning ability, epistemic aims, teaching practices, and vignettes intended to provide an *in-situ* analysis of the previously mentioned measures. The order in which each set of questions was presented to participants was randomized (with the exception of background and demographic information which was always first, and the vignettes which were always last). Furthermore, items within all question sets, as well as answer choices within items were randomized to avoid bias.
Background Information and Demographic Questionnaire

The demographic questionnaire (APPENDIX A) asked for participants’ background information including age, sex, ethnic background, years of teaching experience, level of education, areas of certification, types of certification (traditional versus alternative), and subject areas taught.

Epistemic Beliefs

Participants’ epistemic beliefs about the natural sciences and the learning sciences were assessed using items adapted from Hofer’s (2000) Discipline-Focused Epistemological Beliefs Questionnaire (DFEBQ) (α = .51 - .81; APPENDIX B). All items were adapted to be subject-specific to the subject participants self-reported as their primary subject area. If participants indicated that they teach multiple subjects, they were asked to choose the subject with which they most identify.

Epistemic Aims

Participants’ epistemic aims were assessed using a newly created measure adapted from Chinn et al. (2014) (APPENDIX C). As a newly emerging construct, there are currently no other published measures of epistemic aims. Items were modeled after examples of epistemic aims that Chinn et al. describe in their 2011 and 2014 articles.

Beliefs about Learning Abilities

Beliefs about students’ learning abilities were assessed using items adapted from Dweck’s (1999) Implicit Theories of Intelligence scale (APPENDIX D). The items were adapted for a science context by Perez, Cromley, and Kaplan (2014; reliability = .73 - .90).
Teaching Practices

Participants’ self-reported teaching practices were assessed using the National Science Foundation’s Local Systemic Change initiative as reported in Supovitz and Turner (2000; reliability = .82 - .88; APPENDIX E).

Self-efficacy

Participants’ self-efficacy for teaching science were assessed using items adapted from Tschannen-Moran and Woolfolk Hoy’s (2001) measure of teacher self-efficacy (reliability = .90; APPENDIX F).

Vignettes

Finally, participants read and responded to two vignettes. Vignettes were subject-specific corresponding with the participant’s self-identified primary subject area. The vignettes were meant to elicit elements of the above questionnaires: epistemic beliefs, epistemic aims, learning beliefs, and teaching practices. The first vignette, Mr. Rodgriguez, portrayed a lesson meant to reflect epistemic beliefs about science that are simple/certain knowledge, authority as the source of knowledge, and external justification, as well as transmissionist beliefs about learning and teacher-centered teaching practices. The second vignette, Ms. Brown, portrayed a lesson meant to reflect epistemic beliefs about science that are complex and evolving knowledge, self and others as the source of knowledge and internal as well as external justification, constructivist beliefs about learning, and student-centered, inquiry-based teaching practices.

As participants read the vignettes they were asked to click once on sections of the text with which they identify as a teacher and double click on sections of the text with which they do not identify as a teacher. After reading each vignette, the participants were
Data Analysis

As described above, this study sought to explore two main research questions. I will describe how I analyzed my data in order to answer each of the questions. Table 2 summarizes the research questions and the analytical steps I took in order.

**RQ1a. Do secondary science teachers’ epistemic beliefs about science differ from their epistemic beliefs about how students learn?**

**RQ1b. Do secondary science teachers’ epistemic beliefs about science and how students learn differ by discipline?**

I first conducted an exploratory factor analyses (EFA) for the DFEBQ–Science items and the DFEBQ–Learning items to explore the factor structure of the instruments. I then conducted dependent t-tests to determine if there were significant differences in participants’ beliefs about science and beliefs about how students learn. To determine if beliefs differed by academic subject domain I conducted an analysis of variance (ANOVA), followed by appropriate t-tests.

**RQ2a. How does the level of alignment between secondary science teachers’ epistemic beliefs about science and their epistemic beliefs about how students learn influence their science teaching practices?**

**RQ2b. What role do epistemic aims and self-efficacy play?**

In order to answer research questions 2a and 2b, I conducted a latent profile analysis (LPA) using Mplus (Figure 2 depicts the proposed model). Epistemic beliefs about the natural science and epistemic beliefs about the learning sciences were used to
create the latent profiles, which were used to predict learning beliefs, epistemic aims, self-efficacy beliefs, and ultimately teacher practices.

Table 2

Research questions and analyses

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Analysis</th>
</tr>
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<tbody>
<tr>
<td>Difference between EBS and EBL</td>
<td>1. Exploratory factor analysis</td>
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<tr>
<td></td>
<td>2. Multidimensional scaling</td>
</tr>
<tr>
<td></td>
<td>3. Dependent ( t )-tests</td>
</tr>
<tr>
<td>Difference between EBS and EBL by science subject</td>
<td>4. Analysis of variance</td>
</tr>
<tr>
<td>Profiles of alignment between EBS and EBL</td>
<td>5. Latent profile analysis</td>
</tr>
<tr>
<td>Role of epistemic aims, self-efficacy, and ITI in</td>
<td>6. Structural equation modeling</td>
</tr>
<tr>
<td>relationship between profiles of beliefs and teaching</td>
<td></td>
</tr>
<tr>
<td>practice</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 2.* Proposed LPA model of the relationship between latent profiles based on epistemic beliefs about science and epistemic beliefs about how students learn, and teaching practices.
Person-centered analysis, of which LPA is an example, is gaining in popularity in education research in general (e.g., Wormington & Linnenbrink-Garcia, 2016; Pastor, Baron, Miller, & Davis, 2007) and in research into epistemic beliefs in particular (e.g., Buehl & Alexander, 2006; Barger, Wormington, Huettel, & Linnenbrink-Garcia, 2016). Traditional variable-centered analysis, such as regression and factor analysis, focuses on the relationships among and between variables. The goal of person-centered analysis is to create groups of individuals who are similar to each other on certain variables and different from individuals in other groups (Muthén & Muthén, 2000). Examples include cluster analysis, finite mixture modeling, latent class analysis (LCA), and LPA which will be the analytical method used in this study. In LCA, groups are determined based on categorical variables, whereas in LPA they are determined with continuous variables. The latent profiles in this study were formed using epistemic beliefs about the natural sciences and epistemic beliefs about the learning sciences. These are continuous variables and the analysis therefore is considered a LPA. While much of the literature reports on LCA, the same methods and assumptions are used; the distinction lies in the type of variable used to create the groups (Lanza & Cooper, 2016).

LPA “describes how the probabilities of a set of observed [continuous] variables or indicators vary across groups of individuals where group membership is not observed” with the goal of finding the smallest number of profiles that can describe the relationship between a set of variables (Muthén & Muthén, 2000, p. 883). In the case of this study, the profiles will describe the different combinations of beliefs about the natural sciences and beliefs about the learning sciences; for example, one profile could consist of participants who scored as highly sophisticated on both science and learning beliefs,
while another could consist of participants who scored highly sophisticated on science beliefs but very naïve on learning beliefs. The LPA adds profiles one by one until it achieves optimal model fit. Parameters given provide probabilities of profile membership (Muthén & Muthén, 2000).

In this study, latent profiles were created using participants’ two assessed sets of epistemic beliefs. These profiles were then used as predictors of investigative teaching practices. Since LPA is a model-based analysis, I started with a 2-profile model, assessed goodness-of-fit, and added classes until I achieve adequate fit. I then ran the model with the proposed paths depicted in Figure 2.

*Missing Data*

I explored the frequency and nature of missing data on all variables. If missingness was higher than 50% on either of the epistemic belief measures, that case was removed from future analysis. Mplus handles missing data using Full Information Maximum Likelihood (FIML) estimations.
CHAPTER 4
RESULTS

Epistemic Beliefs

Before analyzing the descriptive statistics, I ran an exploratory factor analysis of both epistemic belief scales separately. Due to the inconsistent results of previous studies using the DSEBQ (Hofer, 2000), and because of the modifications I made to the scale to make it relevant to my study, I ran an exploratory factor analysis in order to understand the factor structure of these measures that were specific to my sample.

*Exploratory item-level analysis*

I ran a principal axis factoring (PAF) with varimax rotation\(^2\) on Epistemic Beliefs – Natural sciences (EBS) and Epistemic Beliefs – Learning Sciences (EBL) separately. Using eigenvalues larger than 1.00 and factor loadings greater than .3, initial PAF yielded four factors that differed slightly from Hofer’s four factor results. My PAF yielded one factor with items assessing certainty, one that combined items assessing source: authority and attainment of truth, and two separate factors each including different items assessing Justification: Personal. When I ran reliability analyses for each of these factors, the Spearman-Brown coefficient\(^3\) for the two personal justification scales were low (EBS: \(r_{SB} = .54, .61\); EBL: \(r_{SB} = .44, .50\)).

\(^2\) I first ran the PAF with an oblimin rotation however, upon seeing uncorrelated factors, I re-ran with a varimax rotation.

\(^3\) Spearman-Brown is the preferred analysis for two-item reliability analysis (Eisinga, Grotenhuis, & Pelzer, 2013).
Multidimensional Scaling

I then conducted a multidimensional scaling (MDS) using squared Euclidean distance in order to deepen my investigation into the meaning participants assigned to these items. First I ran the MDS with all items, and then without the personal justification items. Results of the MDS for EBS items are presented in Figures 3 and 4 and EBL items in Figures 5 and 6. In the EBS MDS, the certainty items captured an overarching region that encompassed the constructs of authority as source and attainment of truth. Personal justification captured a distinct region. The split between the four personal justification items into two pairs reflects the PAF findings that split personal justification into two factors. Furthermore, while two personal justification items (Q33 and Q34) appeared to be in close proximity to the other constructs, they were not encompassed within the certainty region as were the other constructs. In the MDS without the personal justification items (Figure 4), the overlap between the three constructs was retained, suggesting a shared meaning of these constructs that is captured by degree of certainty in epistemological beliefs in the natural science domain.

In the MDS for the EBL items, a similar pattern emerged. In the MDS with the personal justification items, this construct stands alone while the other three are closely related. Again, the PAF results that split personal justification into two factors are reflected in the bifurcation of the pairs of items. In the MDS that omitted the personal justification items, the three remaining constructs were farther apart, although certainty and source: authority remained close together, with attainment of truth much farther away.
Principal Axis Factoring

Based on the results of the initial PAF and the MDS, I omitted the personal justification items from further analyses. I then re-ran the PAF without the Justification: Personal items. For Epistemic Beliefs – Natural Sciences, the PAF yielded three factors accounting for 51.2% of the variance. This scale factored exactly along theoretical lines proposed by Hofer (2000) into certainty, source: authority, and attainment of truth. The overall reliability for the EBS main scale was .80 (14 items). The final factor structure is presented in Table 3. Subscale reliabilities can be found in Table 6.

The PAF for EBL was slightly more complicated. It identified three factors accounting for 49.55% of variance. One item ("I am most confident that I know something about student learning when I know what the experts think.") failed to load on any factor. I eliminated this item and re-ran the PAF. Three factors remained accounting for 52.20% of the variance. Factor 1 contained most items on the Certainty subscale, except for one item ("All experts understand the field in the same way") that cross-loaded with factor 2 (factor loadings of .336 and .618 respectively) and was thus named Certainty. Factor 3 contained all items on the attainment of truth subscale and was thus named attainment of truth. Factor 2 contained most items from source: authority, however, it also contained two items from the certainty subscale that had to do with experts and what experts know. Therefore, I named this factor, Expert Knowledge. One item ("Most problems regarding how students learn have only one right answer.") cross loaded heavily with Factors 1 and 2 (factor loadings of .455 and .446 respectively). I ran the reliabilities with this item as part of both factors and determined that it best fit with
Factor 1 (Certainty). Overall reliability for the EBL main scale was .82 (13 items). The final factor structure is below in Table 4. Subscale reliabilities can be found in Table 6.

**Figure 3.** Multidimensional scaling of Epistemic Beliefs – Natural Sciences including Personal Justification items

**Figure 4.** Multidimensional scaling of Epistemic Beliefs – Natural Sciences excluding Personal Justification items
Figure 5. Multidimensional scaling of Epistemic Beliefs – Learning Sciences including Personal Justification items

Figure 6. Multidimensional scaling of Epistemic Beliefs – Learning Sciences excluding Personal Justification items

Note: Dotted line reflects the inclusion of items in the expert knowledge subscale created from the PAF
Table 3

*Principal Axis Factoring of Epistemic Beliefs – Natural Sciences*

<table>
<thead>
<tr>
<th>Items</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor 1: Certainty</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Truths about [subject] are unchanging.</td>
<td>.655</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Principles of [subject] are unchanging.</td>
<td>.603</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Most of what is true in the field of [subject] is already known.</td>
<td>.578</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All experts in [subject] would probably come up with the same answers to questions.</td>
<td>.506</td>
<td>.387</td>
<td></td>
</tr>
<tr>
<td>All experts in [subject] understand the field in the same way.</td>
<td>.494</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Answers to questions about [subject] change as experts gather more information. (R)</td>
<td>-0.486</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In [subject], most work has only one right answer.</td>
<td>.482</td>
<td>.384</td>
<td></td>
</tr>
<tr>
<td>In [subject], it is good to question the ideas presented. (R)</td>
<td>.398</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Factor 2: Attainment of Truth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>If scholars and scientists try hard enough, they can find the answers to almost anything</td>
<td>.816</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experts in [subject] can ultimately get to the truth.</td>
<td>.621</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Factor 3: Source: Authority</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>If my personal experience with [subject] conflicts with ideas in the textbook, the book is probably right.</td>
<td>.566</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I am most confident that I know something about [subject] when I know what the experts think.</td>
<td>.484</td>
<td></td>
<td></td>
</tr>
<tr>
<td>If you read something about [subject] in a textbook, you can be sure it's true.</td>
<td>.355</td>
<td>.481</td>
<td></td>
</tr>
<tr>
<td>Sometimes you just have to accept answers from the experts in [subject], even if you don't agree with them.</td>
<td></td>
<td></td>
<td>.471</td>
</tr>
<tr>
<td>Eigenvalues</td>
<td>4.37</td>
<td>1.72</td>
<td>1.08</td>
</tr>
<tr>
<td>Percentage of variance explained</td>
<td>31.77</td>
<td>12.30</td>
<td>7.72</td>
</tr>
</tbody>
</table>

Note: Boldface indicates items used to create each subscale. Italics indicate significant high cross-loadings.
Table 4

Principal Axis Factoring of Epistemic Beliefs – Learning Sciences

<table>
<thead>
<tr>
<th>Items</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor 1: Certainty</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Principles about how students learn are</td>
<td>.815</td>
<td></td>
<td></td>
</tr>
<tr>
<td>unchanging.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Truths about how students learn are</td>
<td>.622</td>
<td></td>
<td></td>
</tr>
<tr>
<td>unchanging.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Most problems regarding how students</td>
<td>.455</td>
<td>.446</td>
<td></td>
</tr>
<tr>
<td>learn have only one right answer.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Answers to questions about how students</td>
<td>.451</td>
<td></td>
<td></td>
</tr>
<tr>
<td>learn change as experts gather more</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>information. (R)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Most of what is true about how students</td>
<td>.370</td>
<td>.308</td>
<td></td>
</tr>
<tr>
<td>learn is already known.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>It is good to question the ideas presented</td>
<td>.323</td>
<td></td>
<td></td>
</tr>
<tr>
<td>about how students learn. (R)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Factor 2: Expert Knowledge</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All experts in how students learn</td>
<td>.307</td>
<td>.634</td>
<td></td>
</tr>
<tr>
<td>understand the field in the same way.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>If you read something about how students</td>
<td></td>
<td>.584</td>
<td></td>
</tr>
<tr>
<td>learn in a textbook, you can be sure it's</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>true.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>If my personal experience with how students</td>
<td></td>
<td>.535</td>
<td></td>
</tr>
<tr>
<td>learn conflicts with ideas in the textbook,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>the book is probably right.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All experts in how students learn would</td>
<td></td>
<td>.491</td>
<td>.491</td>
</tr>
<tr>
<td>probably come up with the same answers to</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>questions about how students learn.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sometimes you just have to accept answers</td>
<td></td>
<td>.400</td>
<td></td>
</tr>
<tr>
<td>about how students learn from the experts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>even if you don't understand it.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Factor 3: Attainment of Truth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>If scholars and scientists try hard enough,</td>
<td></td>
<td>.674</td>
<td></td>
</tr>
<tr>
<td>they can find the answers to almost anything</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>in student learning.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experts can ultimately get to the truth</td>
<td></td>
<td>.638</td>
<td></td>
</tr>
<tr>
<td>about how students learn.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eigenvalues</td>
<td>4.21</td>
<td>1.54</td>
<td>1.04</td>
</tr>
<tr>
<td>Percentage of variance explained</td>
<td>32.35</td>
<td>11.86</td>
<td>8.00</td>
</tr>
</tbody>
</table>

Note: Boldface indicates items used to create each subscale. Italics indicate significant high cross-loadings.
Descriptive Statistics

Descriptive statistics showed that item-level, subscale-level, and overall scale-level means of epistemic beliefs in the natural sciences significantly differed from epistemic beliefs in the learning sciences. On the main scales, subscales and item-levels, mean scores indicate a stronger endorsement of the certainty of knowledge, authority as the source of knowledge, and the attainability of truth in the natural sciences than in the learning sciences. Mean scores on personal justification for knowledge were higher in the learning sciences than in the natural sciences.

Item-Level

Item-level descriptive statistics for epistemic beliefs are presented in Table 12 (APPENDIX H). All epistemic belief items fell within the normal range of skewness and kurtosis according to Kline (2010) and were thus normally distributed. All items had a range of 1.00 – 5.00 except for one item (“I am most confident that I know something about how students learn when I know what the experts think.”) which had a range of 1.00 – 4.00. As expected, participants more strongly agreed with statements of knowledge in the natural sciences as being more certain, more deriving from authority or experts, less justified by personal experience, and more likely to attain truth. In the learning sciences participants less strongly agreed that knowledge is certain, derived from authority or experts, is more justified by personal experience, and is less likely to attain the truth.

Subscale-Level

Descriptive statistics at the subscale level for epistemic beliefs are presented in Table 6. Using the normality criteria mentioned above, all the subscales displayed normal
distribution. The EBS – Certainty subscale had a range of 1.50 – 4.63; the EBS – Source: Authority and EBS – Attainment of Truth subscales had a range of 1.00 – 5.00; the EBL – Certainty had a range of 1.00 – 3.83; the EBL – Expert Knowledge subscale had a range of 1.00 – 4.80; the EBL – Attainment of Truth subscale had a range of 1.00 – 5.00. As in the item-level, subscale descriptive statistics revealed higher scores on certainty, authority/expert knowledge, and attainment of truth for the natural sciences ($M = 2.71$ to 3.60) than for the learning sciences ($M = 2.00$ to 3.20). On both measures, participants expressed the lowest scores on certainty of knowledge ($m_{EBS} = 2.71$, $m_{EBL} = 2.00$) and the highest scores on the attainability of truth ($m_{EBS} = 3.60$, $m_{EBL} = 3.20$). Subscale descriptive statistics are presented in Table 6.

Scale-Level

As with the item- and subscale-level, main scales displayed normal distribution with skewness and kurtosis falling within the acceptable parameters established by Kline (2010). EBS had a range of 1.50 – 4.71 and EBL had a range of 1.00 – 4.30. Participants indicated higher scores on the EBS main scale than the EBL main scale ($M = 3.14$, 2.51). Full descriptive statistics for the main scales can be found in Table 6.

Epistemic Aims

I created the epistemic aims scales with the intention of differentiation between different types of aims. Thus, I ran an exploratory factor analysis of this scale to determine the factor structure of these newly created items.

Principal Axis Factoring

I conducted a PAF with an oblimin rotation on the epistemic aims items. Oblimin rotation was selected because I expected the items and the factors to be correlated. Using
eigenvalues larger than 1.00 and factor loadings greater than .3, the PAF yielded two distinct factors accounting for 52.53% of the variance. Factor 1 contained seven items that assess aims that require simpler thinking and reasoning compared to the items in Factor 2. Therefore, I labeled the first factor Simple Epistemic Aims. Factor 2 contained three items that assess aims that required more complex thinking and reasoning compared to items in Factor 1. Therefore, I labeled the second factor Complex Epistemic Aims. The complete PAF results are below in Table 5.

Table 5

Principal Axis Factoring for Epistemic Aims

<table>
<thead>
<tr>
<th>Items</th>
<th>F1</th>
<th>F2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor 1: Simple Epistemic Aims</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explain how [subject] is related to the real-world.</td>
<td>.843</td>
<td></td>
</tr>
<tr>
<td>Explain how [subject] is related to their own lives.</td>
<td>.807</td>
<td></td>
</tr>
<tr>
<td>Understand how [subject] is related to other science topics (e.g., biology, chemistry, physics, Earth science).</td>
<td>.595</td>
<td></td>
</tr>
<tr>
<td>Explain why and how certain phenomenon in [subject] occur (e.g., DNA replication, population growth).</td>
<td>.523</td>
<td></td>
</tr>
<tr>
<td>Understand how [subject] is related to other school subjects.</td>
<td>.417</td>
<td></td>
</tr>
<tr>
<td>Evaluate [subject] models (e.g., natural selection, photosynthesis).</td>
<td>.408</td>
<td></td>
</tr>
<tr>
<td>Learn specific facts about [subject].</td>
<td>.390</td>
<td></td>
</tr>
<tr>
<td>Factor 2: Complex Epistemic Aims</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Challenge students’ alternative conceptions about [subject].</td>
<td>.828</td>
<td></td>
</tr>
<tr>
<td>Question ideas and concepts I teach them about [subject].</td>
<td>.436</td>
<td></td>
</tr>
<tr>
<td>Correct prior false knowledge about [subject].</td>
<td>.385</td>
<td></td>
</tr>
<tr>
<td>Eigenvalues</td>
<td>4.25</td>
<td>1.00</td>
</tr>
<tr>
<td>Percentage of variance explained</td>
<td>42.50</td>
<td>10.03</td>
</tr>
</tbody>
</table>

Note: Boldface indicates items used to create each subscale.
**Descriptive Statistics**

In this sub-section, both item-level and main scale level normality and descriptive statistics are discussed.

*Item-Level*

Item-level descriptive statistics for epistemic aims are presented in Table 12 (APPENDIX H). All epistemic aims items displayed a normal distribution with skewness and kurtosis all falling within the aforementioned acceptable guidelines. All items had a range of 1.00 – 5.00. All aims were endorsed to a relatively high extent ($M = 3.53 - 4.30$, $SDs = 1.03 - .85$). Participants most strongly endorsed the aim “*When teaching [subject], I aim for my students to explain how [subject] is related to the real-world*” ($M = 4.30$, $SD = .85$) and least strongly endorsed the aim “*When teaching [subject], I aim for my students to understand how [subject] is related to other school subjects*” ($M = 3.53$, $SD = 1.03$).

*Subscale-Level*

Both subscales displayed normal distribution as well. Simple Epistemic Aims had a range of 1.57 – 5.00 and Complex Epistemic Aims had a range of 1.00 – 5.00. Participants rated simple epistemic aims higher than complex epistemic aims ($M = 3.97$, $3.75$, $SDs = .64$, .80). Complex epistemic aims had an acceptable reliability of .82, however simple epistemic aims had a reliability of only .66. Table 6 contains full descriptive and reliability statistics for the epistemic aims subscales.

*Scale-Level*

Skewness and kurtosis for the overall scale were within the acceptable range indicating normal distribution. The scale had a range of 2.00 – 5.00. An overall mean of
3.90 indicates that participants endorsed most of the aims to a relatively large extent (as the highest possible score was 5). The reliability of the overall scale was .82 (10 items).

Table 6

Descriptive and Reliability Statistics for Epistemic Beliefs, Epistemic Aims, Self-Efficacy, Implicit Theories of Intelligence, and Teaching Practices

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Min.</th>
<th>Max.</th>
<th>Mean</th>
<th>SD</th>
<th>Skew</th>
<th>Kurt.</th>
<th>Alpha</th>
<th>No. items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epistemic Beliefs –</td>
<td>522</td>
<td>1.5</td>
<td>4.71</td>
<td>2.95</td>
<td>.52</td>
<td>-.13</td>
<td>.35</td>
<td>.80</td>
<td>14</td>
</tr>
<tr>
<td>Natural Sciences</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Certainty</td>
<td>522</td>
<td>1.5</td>
<td>4.63</td>
<td>2.71</td>
<td>.58</td>
<td>.31</td>
<td>-.26</td>
<td>.70</td>
<td>8</td>
</tr>
<tr>
<td>Source: Authority</td>
<td>522</td>
<td>1.5</td>
<td>3.11</td>
<td>.66</td>
<td>-.12</td>
<td>.07</td>
<td>.62</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attainment of Truth</td>
<td>522</td>
<td>1.5</td>
<td>3.60</td>
<td>.81</td>
<td>-.56</td>
<td>.15</td>
<td>.73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Epistemic Beliefs –</td>
<td>522</td>
<td>1.5</td>
<td>4.30</td>
<td>2.32</td>
<td>.52</td>
<td>-.13</td>
<td>.27</td>
<td>.82</td>
<td>13</td>
</tr>
<tr>
<td>Learning Sciences</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Certainty</td>
<td>520</td>
<td>1.5</td>
<td>3.83</td>
<td>2.02</td>
<td>.58</td>
<td>.52</td>
<td>.04</td>
<td>.74</td>
<td>6</td>
</tr>
<tr>
<td>Expert Knowledge</td>
<td>520</td>
<td>1.5</td>
<td>4.8</td>
<td>2.31</td>
<td>.64</td>
<td>.49</td>
<td>.54</td>
<td>.72</td>
<td>5</td>
</tr>
<tr>
<td>Attainment of Truth</td>
<td>519</td>
<td>1.5</td>
<td>3.21</td>
<td>.84</td>
<td>-.36</td>
<td>-.26</td>
<td>.65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Epistemic Aims</td>
<td>488</td>
<td>1.5</td>
<td>3.90</td>
<td>3.07</td>
<td>.62</td>
<td>-.24</td>
<td>-.29</td>
<td>.85</td>
<td>10</td>
</tr>
<tr>
<td>Simple</td>
<td>488</td>
<td>1.5</td>
<td>3.97</td>
<td>3.07</td>
<td>.64</td>
<td>-.47</td>
<td>.32</td>
<td>.82</td>
<td>7</td>
</tr>
<tr>
<td>Complex</td>
<td>488</td>
<td>1.5</td>
<td>3.75</td>
<td>.80</td>
<td>-.28</td>
<td>-.54</td>
<td>.66</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Self-efficacy</td>
<td>492</td>
<td>1.5</td>
<td>6.92</td>
<td>1.15</td>
<td>.39</td>
<td>.56</td>
<td>.88</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>ITI Entity</td>
<td>484</td>
<td>1.5</td>
<td>2.05</td>
<td>.82</td>
<td>.79</td>
<td>.52</td>
<td>.81</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>ITI Incremental</td>
<td>484</td>
<td>1.5</td>
<td>4.18</td>
<td>.58</td>
<td>-.53</td>
<td>.23</td>
<td>.83</td>
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<tr>
<td>Teaching Practices</td>
<td>487</td>
<td>1.31</td>
<td>3.55</td>
<td>.56</td>
<td>-.52</td>
<td>.89</td>
<td>.83</td>
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<tr>
<td>Investigative</td>
<td>487</td>
<td>1.31</td>
<td>3.55</td>
<td>.56</td>
<td>-.52</td>
<td>.89</td>
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<tr>
<td>Teaching Practices</td>
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<tr>
<td>Promoting a Classroom</td>
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<tr>
<td>Culture of Investigation</td>
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<td></td>
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</tbody>
</table>

Self-Efficacy

The self-efficacy short-form scale used in this study has been well validated in previous studies as a single construct. Thus, a factor analysis was not conducted and analysis below is only at the item-level and main scale level.
Descriptive Statistics

Item-Level

Item-level descriptive statistics for self-efficacy are presented in Table 13 (APPENDIX H). All self-efficacy items displayed normal distribution based on their skewness and kurtosis. Most items had a range of 1.00 – 9.00. Two items (“How much can you do to provide an alternate explanation when students are confused about [subject]?” and “How much can you do to craft good questions about [subject] for students?”) had a range of 2.00 – 9.00. Overall, participants’ self-efficacy was high ($M = 6.24 - 7.18$, $SDs = 1.45 – 1.81$). Participants felt most efficacious about crafting good questions for their students and least efficacious in assisting families in helping their children learn about their subject.

Scale-Level

Skewness and kurtosis for the main scale were also within a normal range. The scale had a range of 1.50 – 9.00. The self-efficacy main scale also reflected high self-efficacy ($M = 6.92$, $SD = 1.15$). The reliability of the main scale was .88 (8 items).

Implicit Theories of Intelligence

Descriptive Statistics

In this sub-section, both item-level and scale-level normality and descriptive statistics are discussed. This scale has also been widely used and validated and thus a factor analysis was not conducted.

Item-Level

Item-level descriptive statistics for ITI are presented in Table 13 (APPENDIX H). All implicit theory of intelligence items displayed normal distribution with their
skewness and kurtosis all falling within acceptable parameters. All items had a range of 1.00 – 5.00. Participants disagreed the most with “My students’ ability in learning about [subject] is something they can’t change very much” ($M = 1.98$, $SD = .92$). They agreed the most with “If my students work hard, they can improve their basic ability in learning about [subject]” ($M = 4.36$, $SD = .73$).

**Subscale-Level**

Both the entity and incremental subscales displayed a normal distribution based on their skewness and kurtosis. ITI – Incremental had a range of 2.00 – 5.00 while ITI – Entity had a range of 1.00 – 5.00. As predicted, participants rated incremental higher than entity ($M = 4.18, 2.05$, $SDs = .58, .82$, respectively).

**Teaching Practices**

**Descriptive Statistics**

In this section, item-level, subscale, and main scale level normality and descriptive statistics are discussed for the investigative teaching practices scale. This scale has been previously validated and thus a factor analysis was not conducted.

**Item-Level**

Item-level descriptive statistics for teaching practices are presented in Table 13 (APPENDIX H). All items displayed normal distributed based on their skewness and kurtosis. All items had a range of 1.00 – 5.00. Participants most often used open-ended questions ($M = 4.47$, $SD = .85$) and used field work least often ($M = 2.29$, $SD = 1.09$).

**Subscale-Level**

Both subscales, Investigative Teaching Practices and Promoting an Investigative culture, were normally distributed. The Investigative Practices subscale had a range of
1.00 – 5.00, while the Investigative Culture subscale had a range of 1.25 – 5.00. Participants promoted an investigative classroom culture ($M = 4.12, SD = .69$) more than using investigative teaching practices ($M = 2.99, SD = .69$).

**Scale-Level**

The main scale of overall teaching practices also displayed normal distribution with skewness and kurtosis falling within acceptable parameters. The scale had a range of 1.31 – 5.00. The overall mean was 3.55 ($SD = .56$) indicating that these practices take place slightly more than once or twice a month. The reliability for the main scale was .83 (16 items).

**Correlations**

To gain a preliminary understanding of the relationships between constructs, I conducted bivariate correlations with epistemic beliefs, epistemic aims, self-efficacy, implicit theories of intelligence, and teaching practices. There were many significant correlations among scales and subscales, however most were quite small. Full correlation statistics are presented in Table 7.
Table 7

Subscale-Level Bivariate Correlation of Epistemic Beliefs, Epistemic Aims, Self-Efficacy, Learning Beliefs, and Teaching Practices

<table>
<thead>
<tr>
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<tbody>
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<td>3. EBS – Truth</td>
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<td>.42**</td>
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<td></td>
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<tr>
<td>4. EBL - Certainty</td>
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<td>.18**</td>
<td>.09*</td>
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<td>5. EBL – Expert Knowledge</td>
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<td>6. EBL – Truth</td>
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<td>7. Investigative practices</td>
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<td>-.08</td>
<td>-.00</td>
<td>.04</td>
<td>.12**</td>
<td>.09*</td>
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<td>8. Investigative culture</td>
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<td>.03</td>
<td>-.36**</td>
<td>-.29**</td>
<td>-.09</td>
<td>.33**</td>
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<td>9. Efficacy</td>
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<td>-.03</td>
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<td>11. ITI Entity</td>
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<td>.18**</td>
<td>.08</td>
<td>.50**</td>
<td>.44**</td>
<td>.08</td>
<td>.02</td>
<td>-.36**</td>
<td>-.43**</td>
<td>-.63**</td>
<td>1</td>
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<td></td>
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<td>12. EA – Simple</td>
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<td>.01</td>
<td>.12**</td>
<td>-.30**</td>
<td>-.12**</td>
<td>.05</td>
<td>.25**</td>
<td>.45**</td>
<td>.57**</td>
<td>.35**</td>
<td>-.29**</td>
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<td>13. EA - Complex</td>
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<td>-.11*</td>
<td>.08</td>
<td>-.22**</td>
<td>-.08</td>
<td>.06</td>
<td>.22**</td>
<td>.35**</td>
<td>.46**</td>
<td>.26**</td>
<td>-.22**</td>
<td>-.63**</td>
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</tbody>
</table>

*p < .05; **p < .001

Note: EBS = Epistemic beliefs – natural sciences; EBL = Epistemic beliefs – learning sciences; EA = epistemic aims; ITI = Implicit theories of intelligence
Epistemic Beliefs

All epistemic belief subscales were significantly correlated at the $p < .001$ level (except for one which was significant at the $p < .05$ level) with correlation coefficients ranging from .09 to .56. All EBS subscales correlated with each other between .40 and .49. All EBL subscales correlated with each other between .24 and .56. Correlations among analogous subscales (e.g., EBS – Certainty and EBL – Certainty) ranged from .36 to .40.

Teaching Practices

Investigative teaching practices significantly correlated with EBL – Expert Knowledge, Efficacy, ITI incremental, and both epistemic aims subscales ($r = .12 - .25$) at the $p < .001$ level. It also significantly correlated with EBL – Truth (.09) at the $p < .05$ level. Investigative culture was significantly correlated with everything at the $p < .001$ level except for EBS – Truth and EBL – Truth. It correlated positively with investigative teaching practices, efficacy, ITI incremental, and both epistemic aims subscales ($r = .29 - .46$) but was negatively correlated with everything else ($r = -.36 - -.12$).

Self-Efficacy

Self-efficacy was negatively correlated with the certainty and authority as source/expert knowledge subscales in both EBS and EBL ($r = -.17 - -.38$). It was positively correlated with both types of teaching practices, both types of epistemic aims, and incremental theory of intelligence. It was also negatively correlated with entity theory of intelligence.

Implicit Theories of Intelligence

As expected, entity and incremental beliefs were negatively correlated with each other ($r = -.63$). Both epistemic belief – certainty subscales were negatively correlated with incremental and positively correlated with entity. The same relationship existed for EBL – Expert
Knowledge. Incremental was positively correlated with simple epistemic aims and negatively correlated with complex epistemic aims. Entity was negatively correlated with both types of epistemic aims.

**Epistemic Aims**

Both simple and complex epistemic aims were negatively correlated with EBS – Certainty, EBL – Certainty, and EBL – Expert Knowledge at the $p < .001$ level. They were both positively correlated with both types of teaching practices and with self-efficacy at the $p < .001$ level. They were negatively correlated with each other ($r = -.63, p < .001$)

**Domain and Subject Differences in Epistemic Beliefs**

**Domain Differences**

RQ1(a) asks, *Do secondary science teachers’ epistemic beliefs about science differ from their epistemic beliefs about how students learn?* As seems to be the way with most questions related to epistemic cognition, the answer to this question is not simple. In order to answer question 1(a), I first compared the mean scores of the EBS and EBL main scales. A dependent $t$-test indicated significant differences between EBS and EBL ($t(519) = 25.402, p < .001, d = 1.11$) with participants overall scoring higher on EBS ($M = 3.14, SD = .54$) than EBL ($M = 2.51, SD = .53$) indicating greater belief in the certainty of knowledge, authority as the source of knowledge, and the attainability of truth in the natural sciences than in the learning sciences. However, because of the results of the factor analysis, the scales are not entirely parallel. One item from the EBL scale that originated from the certainty subscale was eliminated because it did not load onto any factors.

The comparisons became less clear when examined at the subscale level. As discussed above, the PAF revealed factor structures for EBS and EBL that were slightly different. While
the EBS subscales aligned precisely according to Hofer’s (2000) original work, the EBL subscales loaded slightly differently, with fewer items in the Certainty subscale, and more factors in the Expert Knowledge subscale (consisting mostly of item intended to measure source: authority according to Hofer [2000]).

Nevertheless, dependent t-tests revealed significant differences between the certainty subscales ($t(519) = 24.52, p < .001$), between source: authority in EBS and expert knowledge in EBL ($t(519) = 24.84, p < .001$), and between the attainment of truth subscales ($t(518) = 9.80, p < .001$), all with higher scores on EBS indicating stronger beliefs in the certainty of knowledge, authorities as the source of knowledge, and in the attainment of truth.

**Disciplinary Differences**

In order to answer research question 1(b) (*Do secondary science teachers’ epistemic beliefs about science and about how students learn differ by discipline?*) I conducted a multivariate analysis of variance (MANOVA) that revealed no significant differences by primary subject taught on the main or subscales of either epistemic belief measure. Wilk’s $\Lambda = .97$, $F(18,1442) = .99, p = .47$, $\eta^2_p = .01$.

**Alignment Between Epistemic Beliefs in Natural and Learning Sciences**

In order to answer RQ2(a) (*How does the level of alignment between secondary science teachers’ epistemic beliefs about science and their epistemic beliefs about how students learn relate to their science teaching practices?*) I used Mplus 7.4 (Muthén & Muthén, 2008-2012) to conduct a latent profile analysis to determine the number of profiles of teachers based on their epistemic beliefs across the two scales. I tested two, three, and four profile models with the main scales, and two, three, four, and five profile models with the subscales in order to determine the number of profiles that best fit the data. The fit comparisons among the scales and models are
presented below in Tables 7 and 8. I used AIC, BIC, adjusted BIC (aBIC), entropy, number of cases in each profile, and interpretability to determine the appropriate number of profiles. There are not cut-offs for AIC, BIC, and aBIC; rather, they are used to compare models with the smallest values being the best fit. Entropy should be as close to 1.00 as possible. Number of cases in each profile should be as close to even as possible in order to have meaningful follow-up analysis. While the 4-profile model with the main scales had the lowest AIC, BIC, and aBIC, and the highest entropy, the fourth profile only contained three cases, making further analysis difficult. Therefore, I selected the 3-profile model with the main scales.

Table 8

*Model fit comparisons for main scales*

<table>
<thead>
<tr>
<th></th>
<th>AIC</th>
<th>BIC</th>
<th>aBIC</th>
<th>Entropy</th>
<th>Class Membership</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 profiles</td>
<td>6069.92</td>
<td>6150.89</td>
<td>6090.58</td>
<td>.68</td>
<td>1 – 263; 2 – 261</td>
</tr>
<tr>
<td>3 profiles</td>
<td>5926.36</td>
<td>6037.16</td>
<td>5954.63</td>
<td>.78</td>
<td>1 – 87; 2 – 364; 3 – 73</td>
</tr>
<tr>
<td>4 profiles</td>
<td>5852.19</td>
<td>5992.82</td>
<td>5888.06</td>
<td>.75</td>
<td>1 – 109; 2 – 291; 3 – 61; 4 - 63</td>
</tr>
<tr>
<td>5 profiles</td>
<td>5801.62</td>
<td>5972.08</td>
<td>5845.11</td>
<td>.74</td>
<td>1 – 51; 2 – 70; 3 – 217; 4 – 148; 5 – 38</td>
</tr>
</tbody>
</table>

Table 9

*Model fit comparisons for subscales*

<table>
<thead>
<tr>
<th></th>
<th>AIC</th>
<th>BIC</th>
<th>aBIC</th>
<th>Entropy</th>
<th>Class Membership</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 profiles</td>
<td>1581.46</td>
<td>1611.29</td>
<td>1589.07</td>
<td>.54</td>
<td>1 – 138; 2 – 386</td>
</tr>
<tr>
<td>3 profiles</td>
<td>1558.04</td>
<td>1600.65</td>
<td>1568.91</td>
<td>.62</td>
<td>1 – 54; 2 – 365; 3 – 105</td>
</tr>
<tr>
<td>4 profiles</td>
<td>1543.87</td>
<td>1599.27</td>
<td>1558.00</td>
<td>.71</td>
<td>1 – 315; 2 – 52; 3 – 154; 4 – 3</td>
</tr>
</tbody>
</table>

I then ran descriptive analyses for the three profiles, comparing the mean EBS and EBL scores. Profile one contained 54 cases that averaged relatively low EBS scores \((M = 2.39, SD = .50)\) and low EBL scores \((M = 1.60, SD = .30)\), indicating beliefs in low certainty, low belief in authority as the source of knowledge, and low belief in the attainability of truth. Profile 2 was the largest with 365 cases that averaged relatively medium EBS scores \((M = 3.10, SD = .42)\) and medium EBL scores \((M = 2.45, SD = .32)\), indicating medium agreement on belief in the
certainty of knowledge, authority as source, and the attainability of truth. Profile 3 contained 105 cases and contained relatively high scores on both EBS and EBL ($M = 3.66, 3.19, SDs = .40, .29$, respectively), indicating a strong belief in the certainty of knowledge, in authority as the source of knowledge, and in the attainability of truth.

Each profile was named using the conventional, albeit problematic, labels pervasive in the field. Those with “sophisticated” epistemic beliefs believe that knowledge is uncertain, they doubt authorities as the source of knowledge, and they have a low belief in the attainment of truth. Those with “naïve” epistemic beliefs believe that knowledge is certain, authorities are the source of knowledge, and truth is attainable. I have labeled the middle profile, “Flexible” as I feel it reflects an unwillingness to commit to either side of the belief spectrum.

A multivariate analysis of variance (MANOVA) indicated that there were significant differences by profile membership. Box’s Test of Equality of Covariance was significant ($p = .02$), therefore Pillai’s Trace, which is robust against non-homogeneity of variance (Olson, 1976), is reported. (Pillai’s Trace $= .74$, $F(4, 1034) = 151.65, p < .001$, $\eta^2_p = .37$.) Follow-up univariate analysis indicated that all three profiles differed from each other on both EBS and EBL main scales and subscales, thus verifying three distinct profiles. All three profiles also differed from each other on ITI – Incremental with Sophisticated rating it highest ($M = 4.40, SD = .65$) and Naïve rating it lowest ($M = 4.03, SD = .55$). Other noteworthy differences include Naïve being significantly lower on self-efficacy than the Sophisticated or Flexible profiles ($M_S = 7.34, SD = 1.29; M_F = 7.03, SD = 1.02; M_N = 6.31, SD = 1.27$) and higher than the Flexible profile on ITI – Entity ($M_F = 1.93, SD = .70; M_N = 2.65, SD = .92$). Additionally, Naïve had the youngest teachers ($M = 34.93, SD = 7.74$), the highest percentage of early career teachers (1-5
years of teaching; 73.3%), the highest percentage of males (66.7%), and the highest percentage of underrepresented minorities (31.5%).

Table 10

Descriptive statistics for key variables by profile

<table>
<thead>
<tr>
<th></th>
<th>“Sophisticated”</th>
<th>“Flexible”</th>
<th>“Naïve”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Cases</td>
<td>54</td>
<td>365</td>
<td>105</td>
</tr>
<tr>
<td>EBS</td>
<td>2.40* .50</td>
<td>3.11* .42</td>
<td>3.64* .40</td>
</tr>
<tr>
<td>Certainty</td>
<td>2.10* .42</td>
<td>2.65* .50</td>
<td>3.23* .52</td>
</tr>
<tr>
<td>Source: Authority</td>
<td>2.49* .68</td>
<td>3.06* .57</td>
<td>3.59* .60</td>
</tr>
<tr>
<td>Attainment of Truth</td>
<td>2.60* .91</td>
<td>3.61* .69</td>
<td>4.12* .61</td>
</tr>
<tr>
<td>EBL</td>
<td>1.60* .30</td>
<td>2.45* .32</td>
<td>3.19* .29</td>
</tr>
<tr>
<td>Certainty</td>
<td>1.37* .35</td>
<td>1.96* .46</td>
<td>2.59* .61</td>
</tr>
<tr>
<td>Expert Knowledge</td>
<td>1.50* .36</td>
<td>2.21* .45</td>
<td>3.08* .57</td>
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<tr>
<td>Truth</td>
<td>1.94* .61</td>
<td>3.18* .69</td>
<td>3.90* .52</td>
</tr>
</tbody>
</table>

Note: * denotes significantly different across all three profiles; † denotes Naïve profile significantly different from Sophisticated and Flexible

4 Underrepresented minorities refer to individuals identifying as black, African-American, Hispanic, Latino, Native American, and/or American Indian. Individuals with this racial and/or ethnic identification are underrepresented in STEM degree programs and fields (National Science Foundation [NSF], 2015).
Table 11

*Descriptive statistics frequencies for key variables by profile*

<table>
<thead>
<tr>
<th></th>
<th>“Sophisticated” (%)</th>
<th>“Flexible” (%)</th>
<th>“Naïve” (%)</th>
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<td><strong>Years Teaching</strong></td>
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<td>3-5 years</td>
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<td>6-10 years</td>
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<td>11-15 years</td>
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<td>16+ years</td>
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<td>44.4</td>
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Role of Epistemic Aims, Self-Efficacy, and Learning Beliefs

To explore the role of epistemic aims, self-efficacy, and learning beliefs in the relationship between profiles of epistemic beliefs and teaching practices, I again utilized Mplus 7.4 (Muthén & Muthén, 1998-2012). The proposed model is presented below in Figure 7. I originally hypothesized epistemic aims as a single construct, however PAF revealed two distinct constructs. Learning beliefs, measured using an adapted Implicit Theories of Intelligence Scale (Dai & Cromley, 2014b; Dweck, 1999), and teaching practices (Supovitz & Turner, 2000) each contained two subscales. Using the probabilities of profile membership generated by Mplus, the software created an output file with each case assigned to the profile in which it had the highest probability of belonging. I used this variable to create two dummy variables, using the Sophisticated profile as the reference category. Dummy variable 1 compared Sophisticated and Flexible and was named “Flexible”, while dummy variable 2 compared Sophisticated and Naïve and was thus named “Naïve.” The revised model is shown in Figure 8.

Figure 7. Initial proposed structural equation model
Figure 8. Operationalization of the initial proposed model with self-efficacy as a moderator between epistemic aims and teaching practices

Figure 9. Operationalization of the initial proposed model with self-efficacy as a mediator
In my model, I hypothesized that epistemic aims would be a mediator between epistemic beliefs and teaching practices. However, Buehl and Fives (2016), in their model of teachers’ epistemic cognition, depict epistemic aims as an antecedent to beliefs. Learning beliefs and self-efficacy were conceptualized as an epistemic stance and an epistemic virtue, respectively, and thus fall under the category of influences on epistemic cognition according to the Buehl and Fives (2016) model. I originally hypothesized self-efficacy to be a moderating variable in the relationship between epistemic aims and teaching practices; a teacher might have a specific aim but will not be able to implement it without the belief in their ability to effectively do so, therefore the relationship between aims and teaching practice would vary depending on the level of efficacy. However, I recognized that as an influence on epistemic cognition and due to prior research demonstrating self-efficacy’s relationship with inquiry-based teaching practices (Uiterwijk-Luijk, Krüger, Zijlstra, & Volman, 2017), it might instead function as a mediator. (Buehl and Fives do not give an indication of how these constructs might fit into a quantitative...
Therefore, using my own hypotheses and the Buehl and Fives (2016) model as guides, I specified two main models, one based on Buehl and Fives and one based on my original proposal of epistemic aims as a mediator between epistemic beliefs and teaching practices. My models are depicted in Figures 8 and 9; the model based on Buehl and Fives is depicted in Figure 10.

In order to assess model fit I used fit statistics generated by Mplus: $x^2$, Root Mean Square Error of Approximation (RMSEA), Comparative Fit Index (CFI), and Tucker-Lewis Index (TLI). In a model with good fit $x^2$ is non-significant ($p > .05$), RMSEA is smaller than .05, and the CFI and TLI and both greater than .95 (Geiser, 2013). I used these criteria in assessing model fit.

The initial Buehl and Fives model had poor fit, even after eliminating non-significant paths: $x^2 (9) = 227.11, p < .001; \text{RMSEA} = .22, 90\% \text{CI} [.20 .25]; \text{CFI} = .62; \text{TLI} = -.15$. (These fit statistics are from the initial model with all paths as depicted in Figure 9, although fit statistics for the model with non-significant paths removed were also poor.)

My initial model also fit poorly: $x^2 (18) = 645.29, p < .001; \text{RMSEA} = .26, 90\% \text{CI} [.25 .28]; \text{CFI} = .32; \text{TLI} = -.32$. After eliminating non-significant paths, I got an improved model fit but one that was still quite low on several metrics: $x^2 (4) = 27.29, p < .001; \text{RMSEA} = .11, 90\% \text{CI} [.07 .15]; \text{CFI} = .90; \text{TLI} = .78$. Previous research has shown a lack of direct coherence between beliefs and teaching practices. Therefore, I did not originally hypothesize a direct effect between dummy variables and teaching practices, however I wanted to test this quantitatively as this conclusion was reached mostly through qualitative research (e.g., Tsai, 2006; Kagan & Wallace, 2005). I re-ran the model with direct effects from Flexible and Naïve to investigative practices and investigative culture. After eliminating non-significant paths the model fit...
moderately well: $x^2(2) = 9.25, p = .01$; RMSEA = .09, 90% CI [.04 .14]; CFI = .97; TLI = .86; SRMR = .04. This model is presented in Figure 11.\(^5\)

![Diagram of the model](image)

**Figure 11.** Final model with direct effects only to investigative culture

As suggested in the Mplus user’s guide (Muthén & Muthén, 1998-2012), I used the stdy standardization for indirect effects with dichotomous categorical variables. Based on the model in Figure 11, there were significant indirect effects from Flexible to investigative practices and from Naïve to investigative culture.

**Alternative Model**

I would be remiss to not report alternative models which also fit the data well. Rather than creating latent profiles, I ran a path analysis using the EBS and EBL main scales as discrete

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\(^5\) Note that this model used the “Sophisticated” profile as a reference category. The model would look different by using a different profile as the reference category. As an example, please see APPENDIX I, Figure 13.
variables, predicting teaching practices with self-efficacy as a mediator as depicted in Figure 12. This model had nearly identical model fit, although the path from EBS to self-efficacy was non-significant. To investigate this model further, I ran the same model with the EBL subscales. The model fit well but the paths from the subscales were all non-significant, probably due to multicollinearity.

*Figure 12. Alternative model with Epistemic Beliefs – Natural Sciences and Epistemic Beliefs – Learning Sciences as discrete variables*
CHAPTER 5
DISCUSSION

Introduction

This study sought to examine middle and high school science teachers’ epistemic cognition and its relationship to investigative science teaching practices. After surveying 524 middle and high school science teachers in the United States, I conducted dependent \( t \)-tests and ANOVAs to determine if participants’ epistemic beliefs in the natural sciences and the learning sciences differed and if they differed by primary subject area taught. Conducting a latent profile analysis I identified three distinct profiles of participants based on their epistemic beliefs in the natural and learning sciences. Using dummy variables, I ran a path analysis with profile predicting two types of teaching practice, exploring the use of self-efficacy, epistemic aims, and implicit theories of intelligence as possible mediators and moderators.

Dependent \( t \)-tests revealed significant differences between participants’ epistemic beliefs in the natural and learning sciences. A series of univariate ANOVAs found no significant differences in epistemic beliefs by primary subject area taught. Path analysis indicated significant direct relationships between profile and classroom culture of investigation and significant indirect relationships to investigative practices.

In this chapter I will discuss each of these findings and their implications for both theory and practice. I will conclude by discussing limitations of this study, as well as future directions of research in this area.
Domain and Subject Differences in Epistemic Beliefs

Research question 1(a) and 1(b) asked if there were significant differences between science teachers’ epistemic beliefs in the natural and learning sciences, and if their beliefs differed by subject (i.e., biology, chemistry, physics, Earth science). I found that there were significant differences between beliefs in the natural and learning sciences on most dimensions of epistemic beliefs, however these beliefs did not differ by subject.

Multidimensional Scaling and Principal Axis Factoring

Using multidimensional scaling and principal axis factoring I explored the factor structure of three measures: epistemic beliefs in the natural sciences, epistemic beliefs in the learning sciences, and epistemic aims. The two epistemic belief measures (Hofer, 2000) have been used in numerous studies and have found various factor structures inconsistent with Hofer’s original findings. This study initially found four factors, only one of which (certainty) was aligned with Hofer’s findings. The other two factors split personal justification into two factors (two items in each) and combined authority as source of knowledge and attainment of truth as a single factor. These last two factors likely loaded together as they both have to do with expert knowledge. While attainment of truth loaded separately on EBS and EBL when I omitted the personal justification items, other items that had to do with experts also loaded on the source: authority subscale in EBL. In one of the pairs of personal justification items that created one factor, both items had to do with first-hand experience. I thought one of these items (“I am more likely to accept the ideas of someone with firsthand knowledge in [subject] than researchers who study the subject.”) would be problematic because of participants’ responses to this item in the cognitive interviews. Nearly all interviewees asked some version of “Don’t researchers also have
firsthand experience?” This item was likely confusing for participants in the main study as well. The other personal justification factor contained two items that had to do with subjectivity.

Other studies found different factor structures using Hofer’s (2000) measure. Topcu (2013) found three factors measuring certainty and personal justification separately, with source: authority and attainment of truth loading onto the same factor. Choi (2013) found four factors, two measuring a combination of certainty and personal justification, and one each measuring source: authority and attainment of truth. However, Kienhues, Bromme, & Stahl (2008) found two factors that they named stability and certainty/simplicity. Given the varied factor structures that emerged from these various studies, further research is needed into the validation of this measure.

While the present study did not find any significant differences between subjects, one study using the same measure (Hofer, 2000) found significant differences in subject-specific epistemological beliefs in biology, chemistry, and physics in pre-service science teachers (Topcu, 2013). There were some distinct differences between my study and the latter study. For one, all participants in the latter study answered questions about all three subjects during the same implementation of the instrument. In my study, teachers only answered questions regarding the subject with which they most identify. Topcu conducted follow-up interviews to ask participants about their answers to survey questions to provide expanded meaning to their answers. The findings from the qualitative portion of his sample supported the quantitative findings. This could be a future direction of research for the current study.

The MDS analysis of both measures supported the findings of the PAF with two pairs of personal justification items. Additionally, the separation of the personal justification items from the other sets of items supported my decision based on the low reliabilities to exclude these four
items from future analysis. The strength of the subsequent PAFs and MDSes support this decision, although future research should investigate the meaning of personal justification for different people, particularly science teachers. The MDS for EBL without personal justification does raise one question. While in the MDS for EBS, there is clear overlap/connection between the three constructs, the same cannot be said of EBL. In Figure 6, the attainment of truth items are relatively far from the other two constructs. Source: authority and certainty are close to each other but do not display the same level of overlap seen in EBS. However, if you include the two items from certainty that loaded with the source: authority items in the PAF, source: authority occupies a larger space on the grid and it overlaps slightly with certainty. This can be seen in the dotted lines in Figure 6. The EBL attainment of truth subscale had the lowest reliability of the EBS subscales, which could explain its distance from the other two constructs.

The structural differences between the MDS and PAF in EBS and EBL indicate that participants have a clearer more integrated sense of epistemic beliefs in the natural sciences than they do in the learning sciences. This could also be reflective of the perception of that natural sciences as a “hard,” more defined discipline. I hypothesize that, while participants are not used to reflecting on these types of beliefs, they are especially unaccustomed to thinking about these types of beliefs in the learning sciences, a body of knowledge they probably have not considered very much as its own domain. This could also be because of the way I adapted the items to fit my subject-specific context. The terms “how students learn” and “student learning” were sometimes awkward or clunky when substituting them into the item statements in place of the original wording of “field.” I chose not to use the term “learning sciences” as I did not think this would be a widely enough recognized term that most science teachers would understand.
Descriptive Statistics

As expected, participants believed more strongly in the certainty of knowledge, authority as the source of knowledge, and the attainment of truth in the natural sciences than in the learning sciences. While EBS – Certainty was higher than EBL – Certainty (2.71, 2.02), I was surprised that EBS – Certainty was so low. This indicates that, overall, science teachers do not view scientific knowledge as very certain and only marginally more certain than knowledge in the learning sciences. Although not included in subsequent analyses, EBL personal justification was higher in the learning sciences \( (M = 3.47) \) than the natural sciences \( (M = 2.77) \), almost a full point difference. This supports my hypothesis that teachers use personal justification for their basis of knowledge when considering how students learn. Numerous prior studies also found that individuals’ believe knowledge in the “hard” sciences is more certain, externally sourced, and attainable than knowledge in the “soft” sciences. Hofer (2000) found this in her comparison of psychology and science. Barzilai and Weinstock (2015) had similar findings in their comparison of biology and history.

Relationship of Beliefs to Practice

The second research question sought to explore the relationship between beliefs and investigative science teaching practices. I ran two main models, one based on Buehl and Fives’ (2016) model of teacher epistemic cognition, and one based on my own hypothesis of interaction. The Buehl and Fives model did not fit the data well, even after removing non-significant paths. In my own model, I found significant direct and indirect relationships between profiles, investigative practices, and investigative culture, with self-efficacy serving as a mediator.
Descriptions of Profiles

To determine distinct groups of participants based on their epistemic beliefs in the natural and learning sciences, I conducted a latent profile analysis (LPA) using Mplus version 7.4 (Muthén & Muthén, 1998-2012). Based on information criteria, entropy, and meaningfulness, a 3-profile model best fit the data. The three profiles were, as expected, statistically different from each other on all main and subscales of EBS and EBL. Profile 1 displayed the lowest across both EBS and EBL and would be classified as the most “sophisticated” profile. Profile 2 was in the middle and was labeled “Flexible”, and profile 3 had the highest scores on both, thus termed the most “naïve” profile. Additionally, the three profiles differ in their use of practices encouraging a classroom culture of investigation. Profile 1 (“Sophisticated”) reported the highest usage ($M = 4.44, SD = .62$), followed by Profile 2 ($M = 4.16, SD = .63$), then Profile 3 ($M = 3.80, SD = .81$).

There were no differences by profile on investigative teaching practices.

In accordance with previous research, the “sophisticated” profile had the highest reported uses of practices encouraging a classroom culture of investigation and the most “naïve” profile had the lowest. If one holds “sophisticated” beliefs about knowledge as less certain, less sourced from authority, and less of a belief in the attainability of truth it makes sense that they would also encourage a culture of investigation. They see ample room for investigation and for students to discover or even create knowledge themselves. Conversely, those in the naïve profile who have greater beliefs in certainty, authority as the source of knowledge, and the attainability of truth see less room for investigative practices because knowledge is already known and can only be derived from authorities, not from students themselves. Tsai (2006) found similar relationships; teachers in his sample who exhibited constructivist scientific epistemological views (SEVs) allowed more time for student inquiry and interactive discussion. Conversely, teachers who held
more positivist SEVs focused more time and attention on student grades and teacher-led lectures. Similarly, Kang & Wallace (2005) and Hashweh (1996) also found that teachers who held more naïve epistemological beliefs also used more close-ended inquiry, structured labs, and lectures.

Surprisingly, self-efficacy was significantly lower for the naïve profile compared to the sophisticated and flexible profiles. Those in this profile feel more certain about knowledge in both the natural and learning sciences but feel less efficacious in their ability to teach it. Few studies have explored self-efficacy and epistemic beliefs. (Please see the section below entitled Role of self-efficacy for a further discussion of self-efficacy and epistemic beliefs.)

Also noteworthy is the gender distribution between profiles. Profiles 1 and 2 contained 44-50% males while profile 3 contained 67% men. Hofer (2000) also found that men in her sample exhibited more certainty and stronger belief in authority as source. Other studies have found inconsistent results regarding gender and epistemic beliefs. Some studies found no significant differences by gender (Munthe, 2001; Fulmer, 2014; Bråten, Gil, Strømsø, Vidal-Abarca, 2009) with Buehl, Alexander, and Murphy (2002) suggesting that gender differences in epistemic beliefs are more likely to appear when assessing domain-general epistemological beliefs. While this is true of some studies that have found differences by gender (e.g., Schommer, 1993; Schommer & Dunnell, 1994), others studies, the present study included, found gender differences using domain-specific measures (e.g., Hofer, 2000; Enman & Lupart, 2000).

The profiles also differed on Implicit Theories of Intelligence. All three profiles were significantly different from each other on incremental theory of intelligence with the sophisticated profile scoring the highest \( (M = 4.40, SD = .65) \) and the naïve profile scoring the lowest \( (M = 4.03, SD = .55) \). As expected given the inverse relationship of incremental and entity beliefs, the naïve profile \( (M = 2.65, SD = .97) \) displayed significantly higher entity beliefs than
the sophisticated profile ($M = 1.69, SD = .70$) and the flexible profile ($M = 1.93, SD = .70$). While overall, the teachers had relatively high incremental views of intelligence and relatively low entity views of intelligence, the differences between profiles seem logical in that those who have more certain views of knowledge as derived from authorities would see student ability as less malleable and those who view knowledge as less certain and less derived from authority would also believe there is more flexibility in students’ abilities changing.

The naïve profile also had the youngest teachers ($M = 34.93, SD = 7.74$) and the highest percentage of early-career teachers (72% within their first five years of teaching). Prior studies have found that epistemic beliefs become more sophisticated with age (Perry, 1970; Baxter Magolda, 1992), however, most of these studies were done with participants up to thirty years old. While the younger mean age of those in the naïve profile could be influencing their beliefs, more research is needed on the development of epistemic beliefs into adulthood. Prior research has also found more naïve beliefs in teachers associated with fewer years of teaching experience (Olafson, Schraw, & Veldt, 2010). Tsai (2006) found that more experienced teachers in his sample were more likely to have “nested epistemologies,” meaning coherence in beliefs across belief systems. For some of these experienced teachers their nested epistemologies were sophisticated, while some were naïve. The profiles derived from my sample also displayed nested epistemologies; those in the sophisticated profile had scores on both EBS and EBL that were lower than the other two profiles, followed by the flexible profile, and finally, the naïve profile. I did not find the misalignment (or lack of nestedness, to borrow from Tsai) that I expected to between EBS and EBL.

Finally, the profiles differed on ethnic and racial composition with the highest percentage of underrepresented minorities in the naïve profile. Numerous reports and studies have found that
minorities (particularly African-American and Hispanics) are underrepresented in STEM fields (hence the designation as an underrepresented minority; NSF, 2015). Furthermore, studies have found differences by ethnicity and race on scientific literacy with Caucasians outperforming African-Americans and Hispanics on measures of scientific knowledge (Fung & Goo, 2015). Prior research has shown that scientific knowledge can have an impact on your attitudes towards science (Allum, Sturgis, Tabourazi, & Brunton-Smith, 2008), which could explain the ethnic and racial differences by profile.

Path Analysis

Next, I sought to determine the relationship between profile membership and teaching practices, incorporating epistemic aims, implicit theories of intelligence, and self-efficacy as hypothesized mediators and moderators. I hypothesized that this was because there was some missing intermediary. I had thought it was epistemic aims or learning beliefs, with self-efficacy playing a different role, however self-efficacy turned out to be the key factor in this sample, bridging the gap between teachers’ beliefs and practice, for one profile of participants.

Lack of Evidence for Role of Epistemic Aims

Research on epistemic aims is still nascent. In developing my own measure of epistemic aims, I hoped to expand on the work of Chinn et al. (2011, 2014) and Dai (2014). I originally conceptualized my measure of epistemic aims as containing simple and complex aims. The results of the PAF mostly supported this intention, however not in the way I expected. When developing the items, I used aims explicitly referenced in Chinn et al. (2014) drawn from the philosophical literature, such as knowledge⁶, understanding, explanation, and evaluation. In the

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⁶ For the epistemic aim of knowledge, I used the verb “learn” as I felt an item that read “learn facts about [subject]” was more specific and colloquial than an item that read “gain knowledge about [subject].”
literature, there is a distinction between the aims of understanding and explaining. Understanding involves “explanatory connections between items of information” (Kvanvig, 2003, p. 193), whereas explaining involves seeking deeper root causes of phenomenon. Using these definitions, explanation would be a comparatively more complex aim than understanding, which would more a more complex claim than knowledge. In actuality, it does not appear that the teachers in this sample understood or made the distinction between knowledge, understanding or explaining, as all of these items loaded onto the same factor. Evaluation was one other complex aim that also loaded onto simple epistemic aims. The other three aims about challenging alternative conceptions, correcting prior false knowledge, and questioning ideas from the teacher (an authority) all loaded together, as expected.

There is scant literature to support or challenge these findings, due to epistemic aims’ infancy as an empirical construct. Many articles have discussed the relationship between epistemic aims and other motivational constructs such as achievement goal theory. Dai’s (2014) study measured both of these constructs and did, in fact, find them to be distinct. However, given the variety of possible epistemic aims teachers could set, more research must be done to develop an appropriate measurement instrument. Additionally, Chinn et al. (2014) discuss the interplay between epistemic and non-epistemic aims, as do others (e.g., Sandoval, 2016). A deeper understanding of all the aims teachers set will aid in clarifying the relationship between beliefs, aims, and practice.

In their model, Buehl and Fives (2016) depict epistemic aims as occurring or being activated in the cognitive process prior to the processing of beliefs (see Figure 10). While in my original model I proposed testing epistemic aims as a mediator between beliefs and practice, I also ran models with epistemic aims as the independent variable and beliefs as the mediator.
None of the models found evidence for the necessity of the inclusion of epistemic aims as they were measured in this study. I found support for the three lower components of Buehl and Five’s (2016) model: epistemic cognition, influences on epistemic cognition, and epistemic product.

**Influences on Epistemic Cognition**

Buehl and Fives (2016) discuss the importance of influences on epistemic cognition. These influences include, among others, existing epistemic stances and epistemic vices and virtues. For the purposes of this study, I conceptualized learning beliefs as an existing epistemic stance and self-efficacy as an epistemic virtue (M. Buehl, personal communication, August 6, 2016).

*Role of learning beliefs.* Similar to epistemic aims, learning beliefs, as measured by entity and incremental theories of intelligence, were not a well-fitting construct in the model. The findings from the present study support prior research that suggests ITI and epistemic beliefs are distinct and only moderately related (Bråten & Strømsø, 2005).

*Role of self-efficacy.* The final path model in this study indicates that, compared to the sophisticated profile, participants in the naïve profile have lower self-efficacy (.91 SDs lower) and are less likely to engage in both investigative teaching practices (.21 SDs less likely) and practices encouraging a classroom culture of investigation (.45 SDs less likely). This is supported by a significant direct relationship between Naïve and classroom culture, indicating that those in the naïve profile are .61 SDs less likely to engage in investigative culture. There was no direct relationship between Naïve and investigative practices. The flexible profile, as compared to the sophisticated profile, also had a significant relationship to classroom culture of investigation, indicating .28 SDs lower frequency of practice. The flexible profile did not have a significant indirect relationship to either teaching practice through self-efficacy.
The significant direct relationship between profile of beliefs and teaching practice clarifies the literature that has found mixed or inconclusive results when exploring relationships between beliefs and practice and supports the studies that did find a link between the two. As predicted, using a person-centered analysis, as opposed to a variable-centered analysis, highlighted distinct profile differences that led to differential pathways to teaching practices. While there was a direct relationship to one type of teaching practice (investigative practices), the inclusion of self-efficacy indicated a significant indirect relationship to another type of teaching practice (investigative culture).

I will start by explaining the direct relationships. If one views knowledge as certain and sourced from authority (as those in the naïve profile do), then what is known is already known. It is conveyed to students through textbooks and lectures (i.e., from the experts). If knowledge is certain (i.e., already known) and the source of that knowledge is an authority figure, that implies that students cannot create any new knowledge, nor can they or their experiences be the source of this knowledge. This leaves little room for students to conduct their own investigations or come to their own conclusions about scientific knowledge.

But why are the paths to the two types of teaching practices different? This could be partly due to how the questions were worded. The investigative practice items start with the stem “How often do students in your class…” whereas the investigative culture items start with the stem “How often do you…” The difference in agency between the student and the participant (self) could have impacted their answers. Future research could re-phrase the stem in the investigative culture items to read “How often do you have students in your class…” to keep the acting agent in each question set the same. There are also differences in the type of practice asked about in each set. The practices in investigative practice could be perceived as more
definitive and clear if teachers do them and how often. The practices in investigative culture, on the other hand are vaguer. Two items ask how often they “encourage” students to do various tasks. The act of encouraging an activity is less clear than, for example, working on a portfolio and might therefore be more susceptible to social desirability bias.

Explaining the indirect relationships between profile and practice is more complicated. Why would naïve epistemic beliefs predict lower self-efficacy? Prior research on the relationship between beliefs and self-efficacy is unclear. Studies have treated the relationship between epistemic beliefs and motivation differently. For example, Bråten and Strømsø (2005) used self-efficacy as one measure of self-regulated learning and found more naïve epistemological beliefs to be predictive of lower self-regulation. Buehl & Alexander (2006) used ability beliefs (a construct similar to self-efficacy) as part of a measure of motivation and similarly found those with more naïve EBs had less motivation. While neither of these studies use self-efficacy exactly as I did in this study, it provides some support for my findings. Unfortunately, neither of these studies provides much insight into why this might be. For my own understanding, I went back to the items. The items in the Source: Authority (e.g., “If my personal experience with [subject] conflicts with ideas in the textbook, the book is probably right.” “Sometimes you just have to accept answers from the experts in [subject], even if you don’t agree with them.” “I am most confident that I know something about [subject] when I know what the experts think.”) subscale imply deferment of personal agency in the knowledge creation and understanding process. This deferment of agency could indicate less confidence in one’s ability. If I am a teacher in the naïve profile and I believe that authorities are the source of knowledge, it then begs the question, “am I an authority?” The way the items are worded creates distance between the participant and the “experts.” This implies that I distance myself from the experts and defer to their knowledge. If I
am not an expert then I am not a legitimate source of knowledge and information for my
students, hence I am more likely to have lower self-efficacy. Conversely, if I am a member of the
sophisticated profile, I do not strongly endorse these items. That means I reject the distancing of
myself from the “experts.” If I see myself as an expert, both in science and in teaching, that lends
itself to higher self-efficacy.

Alternative Models

Given that the intent of this paper was to investigate the alignment of different systems of
epistemic beliefs and their relationship with teaching practices, a full exploration of EBS and
EBL as discrete variables in a path analysis would not align with the study goals. However,
given the suggestive but inconclusive findings from the alternative model, further investigation
needs to be done to clarify the significance of this and other possible alternative models and
whether profiles of beliefs do provide better fit and better explain the relationship between
beliefs and practices than discrete variables.

Implications

Implications for Theory

Many studies have attempted to find significant relationships between teachers’ beliefs
and their classroom practices with mixed results. Most of these studies are qualitative. This study
significantly adds to theory by adding nuance and support to aspects of epistemic cognition
theory and models. While Chinn et al. (2014) and Buehl and Fives (2016) propose the inclusion
of epistemic aims as a part of epistemic cognition, this study did not find support for epistemic
aims as part of the relationship between beliefs and practice. The theoretical contribution this
study makes is two-fold. First, the findings from this study suggest that epistemic beliefs and
cognition should be studied from a person-centered perspective, rather than a variable-centered
perspective. While variable-centered studies have found weak or non-existent relationships between beliefs and practice, the person-centered approach taken in this study found that teachers have different profiles of belief systems that differentially predict their teaching practices. Second, the inclusion of self-efficacy was instrumental in finding an indirect relationship between belief profile and one type of teaching practice measured in this study, indicating the importance of influences on epistemic cognition. The path from belief to action does not happen in a vacuum and this study emphasizes the importance of considering other factors in the relationship.

Implications for Practice

This study found that teachers in this sample with more years of teaching experience utilized both types of teaching practices more frequently (see Table 10). The implication for this is more support for early career teachers to 1) manage and adjust to the day to day demands of being a lead teacher to increase their self-efficacy, and 2) think about scientific knowledge in a more complex way and how to integrate investigative practices that will support this type of scientific thinking in their students. Early career teachers tend to value educational practice over theory, even if they equally valued both in their pre-service education (Allen, 2009). However, with more support, early career teachers could spend more time reflecting on and implementing classroom practices that encourage complex scientific thinking in their students. This is one of the goals of the movement to support the teaching of the nature of science and is incorporated into the Next Generation Science Standards (NGSS). As NGSS and nature of science become a larger part of science teachers’ pre-service training, they will hopefully encourage the same investigative thinking in their students and choose classroom activities that will reflect that.
Some of the more recent literature on epistemic beliefs and epistemic cognition questions that long-held false dichotomy of naïve versus sophisticated epistemic thinking. Naïve beliefs refer to a stronger belief in the certainty of knowledge, authority as source, and the attainment of truth, whereas sophisticated beliefs refer to less certainty in knowledge, less validity of authority as source, and less of a belief in the attainability of truth. Many scholars have called this into question, not only because it minimizes the nuance people might express in their beliefs, but it also is not always better (i.e. more sophisticated) to believe in the uncertainty of scientific knowledge (e.g., evolution, climate change). This necessitates a simultaneous commitment to and flexibility with scientific knowledge. Similarly, it would be unrealistic and irresponsible to not believe that authorities are the source of at least some knowledge. While we should cross-check our information and the reliability and credibility of sources of information, a single person cannot be an expert on everything. To be a responsible and confident consumer of information, one must rely on experts/authorities who know more than we do.

Bråten, Strømsø, and Samuelstuen (2008) provide a perfect example of this phenomenon in action. In their study of 135 Norwegian undergraduates, students holding sophisticated beliefs about the complexity of knowledge about climate change performed better on a task of multiple-text comprehension. However, those with “sophisticated” views of source beliefs of knowledge about climate change as personally constructed did worse on multiple-text comprehension. Optimal performance on this task required an epistemic flexibility to hold beliefs traditionally viewed as sophisticated about the complexity/simplicity of knowledge and to simultaneously hold beliefs traditionally viewed naïve about the source of knowledge as originating from experts.
How do we teach people to be epistemically flexible when forming beliefs about scientific knowledge? This is a complex concept to grasp and probably not developmentally appropriate for children below a certain age. However, teaching science as truth, as unquestionable fact at an early age will be problematic down the line when students will need to adjust their thinking to be more flexible. Developmentally, this is a challenge, as students typically do not develop abstract thinking until mid-adolescence (Christie & Viner, 2005). Future research must focus on developing developmentally appropriate ways to teach epistemic flexibility, how to determine the reliability of sources, valid criteria for truth, and how scientific knowledge is actually developed. I alter my focus slightly here from teachers to students because this process is cyclical. Many limiting beliefs that teachers hold that result in limited practice come from their early experiences in the classroom as a student. Therefore, this process of learning to be responsible consumers and creators of information must start somewhere. I emphasize teaching students that they can be creators of knowledge because this will empower students to feel like they know things and they can discover new things. This is a central belief of a future scientist and may make the prospect of going into a scientific profession less daunting. If a student learns at an early age that there are still many unknown things about the world and that they can create new knowledge and add to this body of knowledge, that creates less distance between the individual and the scientific community. This empowers the individual to see themselves as a contributor to the collective knowledge that science builds over time to form what eventually becomes widely accepted as a “fact.”

This relates to Kuhn’s developmental approach to epistemic cognition which posits three developmental stages of epistemic thinking: absolutism, relativism, evaluativism (Kuhn, 2001). In the situation I presented above, you have teachers who are either absolutists (belief in the
complete certainty and objectivity of truth) or relativists (believing that all knowledge is relative and a matter of opinion with no grounding in truth or fact) and what we want is evaluativists, teachers who can evaluate different pieces of information, weigh the validity of sources, and convey a sophisticated epistemic flexibility. I feel this calls for less research into the dimensional approach to epistemic cognition (What is its content and structure?) and more research using the developmental approach and interventions that encourage evaluative thinking.

Limitations

The findings and implications of this study should be considered in light of some limitations. First, I was not able to recruit enough participants using the intended snowball sampling strategy. I resorted to data collection using mTurk. While I included numerous stringent screeners, some fake responses still got into the sample. I was able to identify many of them, however it is possible that some slipped through. While not necessarily a limitation, it is important to note that there were significant differences between the “snowball” sample and the mTurk sample on EBS and EBL main scales. This could be reflective of fake responses (i.e., responses from individuals who are not actually teachers) or that there really are substantive differences between the two samples. The sample over-represents teachers from the life sciences (particularly biology) as opposed to the physical sciences. Although there were no significant differences in EBS or EBL between subjects, this bias may have affected the findings as previous studies have found differences between epistemic beliefs in the physical and life sciences (Topcu, 2013). My sample was also overwhelming white/Caucasian (~74%). This however, is slightly below the national average (82.7%; Goldring, Gray, & Bitterman, 2013). Based on the results of the most recent School and Staffing report, 6.4% of all teachers are black, 7.5% Hispanic, 1.8% Asian, .1% Native Hawaiian/Pacific Islander, .4% American Indian/Alaska
Native, and 1.0% multiracial. My sample included more black, Asian, and multiracial teachers, but fewer white and Hispanic teachers. While demographics specific to middle and high school science teachers were not available, reports state that minority representation in STEM teachers is even lower than in the general teaching population (Deruy, 2013).

Another important consideration regarding the sample is the self-selecting nature of the participants. While there was a modest stipend, all participants had some interest in participating in the research. The sample is characterized by relatively high self-efficacy. In future research I would like to explore how the epistemic cognition of specific populations of teachers such as master teachers, pre-service teachers, and/or early career teachers.

While significant relationships between constructs were found, the strength of some of those relationships was weak. The correlation matrix demonstrates medium to low correlations between nearly all constructs used in the analysis. This signifies that the constructs, as measured in this study, may not have much to do with each other. The measure of epistemic beliefs that I used (Hofer, 2000) has found inconsistent results with factor structures and reliability varying across studies (e.g., Topcu, 2013; Choi & Kwan, 2012). I made what I thought were improvements to the study by making each item include the topic about which it was referring in the sentence (e.g., “Principles in biology are unchanging.” as opposed to the original, “Principles in this field are unchanging.”). When adapting the items for the learning sciences set, some of the language may have gotten a little clunky, as came up during the cognitive interviews of the pilot study. I made minor tweaks but struggled to clarify the language while maintaining the parallelism between the items in EBS and EBL.

The instrument I used to measure epistemic beliefs perhaps did not capture my phenomenon of interest, which may explain why I did not find the misalignment between EBS
and EBL that I expected to find. In closely examining the items and how I adapted them for each
domain, both sets of items ask about the scholarship of the natural or learning sciences. When
asked about these two domains within a small timeframe, it could explain why their responses
were parallel. When I began this study, I expected to find that teachers’ personal justifications,
opinions, and anecdotes of how to teach would be highly influential in their instructional
decision-making, and I still believe that they are. However, I do not think I asked about that in
the best way. Future qualitative work will shed light on this distinction and how I and other
researchers might construct instruments that will better capture the beliefs underlying their
instructional decision-making.

Another limitation of this study is that the model with latent profiles comprised of beliefs
fit the model almost as well as an alternative model that depicts EBS and EBL as separate,
observed constructs. This calls into question the hypothesis I hoped to explore about how belief
systems in different domains interact to result in different outcomes. By using latent profiles, I
found meaningful differing groups of participants who engaged in more or less frequent
investigative science practices (depending on their self-efficacy).

Another limitation is that I failed to find any meaningful relationships between epistemic
beliefs, epistemic aims, and teaching practices. I have considered that this may be due to how I
measured epistemic aims. When I created the items, I intentionally chose key aims that are
theoretically distinct in the literature (“understand,” “evaluate,” “explain”). However, teachers
failed to distinguish between the aims themselves and focused instead on the content of the item.
For example, two items asked to what extent teachers aim for their students to “understand” how
their subject is related to other science topics and how it is related to other school subjects. Two
other items asked teachers to what extent they aim for their students to “explain” how their
subject is related to the real world and how it is related to their own lives. These items all grouped together indicating that teachers either 1) do not distinguish between the aims of understand and explaining, 2) when reading the items, focused more on the latter part of the statement (relating material to something else) than they did on the specific aim, or both.

Further, when Chinn et al. (2014) wrote about epistemic aims, they wrote specifically in about an individual’s aims for their own knowledge and knowledge acquisition, not their aims for someone else. When considering a teacher’s epistemic aims for their students, that is what knowledge and knowledge acquisition that want their students to develop, the same constructs and relationship to beliefs and practice may not exist. In this sense, the aims are about knowledge dispersion and facilitation, rather than aims for acquisition as Chinn et al. wrote about.

Another limitation of this study is that there were relatively high ratings on all items measuring epistemic aims, self-efficacy, and teaching practices, indicating social desirability bias. I tried to hedge the impact of social desirability by asking “to what extent do you endorse the following aims?” and “How frequently do you use the following teacher practices?” rather than asking “Do you endorse these aims?” or “Do you use these teaching practices?” with a 1 – 5 Likert scale indicating level of agreement. I do not have a comparative sample to say if this had any impact, but regardless, the preferred answers were clear and whether teachers honestly think and do the things they said they think and do or not is the subject of another study.

These findings should all be interpreted with caution, as model fit was slightly less than ideal and all data was collected at the same time. The intention is never to prove causality in the relationships between epistemic beliefs and practice. All items, including teaching practices, were self-report and collected at a single time point. Therefore, all this study does is demonstrate the connective relationships between the teachers’ beliefs about knowledge, their beliefs about
their teaching abilities, and their beliefs about how they teach at a single point in time. While studies have suggested coherence between self-reported teaching practices and observed teaching practices (e.g., Burnstein et al., 1995; Porter, Kirst, Osthoff, Smithson, & Schneider, 1993; Mayer, 1999) self-report measures can still be problematic, as can suggesting causality with only one time point of data. This could be remedied by collecting data about the teachers’ beliefs, self-efficacy, aims, and teaching practices at two, or preferably three different time points, thereby obtaining longitudinal data to determine how beliefs lead to aims or self-efficacy which lead to frequency of investigative teaching practices.

Future Directions

This study suggests numerous future directions for research. To begin, there are potential co-variates that I identified in my research that I plan to further pursue. As mentioned above, in addition to having the most naïve epistemic beliefs and the lowest self-efficacy, profile 3 also had the youngest teachers and the highest percentage of early career teachers (3 – 5 years of experience), and males. Age, years of teaching experience, and gender have all been found to impact epistemic beliefs and could play a role in the epistemic cognitive process.

Second, I plan to analyze the results of the vignette analysis. During the pilot study, nearly all participants stated that this was the most engaging part of the study. Given that this type of methodology has not been widely used, I am anxious to analyze the results and see how they relate to the findings from this current study. I feel this type of analysis has the potential to be a scalable way to analyze large samples of data on in-situ manifestations of epistemic beliefs, aims, and teaching practices. I also plan to cross-reference this data with the measures of investigative practice and investigative culture.
Considering the highly contextual nature of epistemic cognition, in future research I would like to explore priming the participants with some context at the beginning of the survey, rather than at the end like I did in the current study. By moving the vignettes to the beginning of the questionnaire, it would provide some context and prime the participants to begin reflecting on their teaching practices, their aims, and the beliefs that underlie them. Given the debate over the implicit or explicit nature of epistemic beliefs (Fives & Buehl, 2012), starting the survey with the vignettes, wherein they are reading and thinking about another teacher’s beliefs and practices. may provide an appropriate avenue to prompt participants to begin reflecting on their own beliefs and practices.

Third, I plan to conduct in-depth interviews with a subsample of teachers from this study. Interviewees will be selected in order to obtain diversity in gender, race, geographic region, subject area, beliefs, aims, and self-efficacy. These interviews will delve deeper into the sub-constructs of epistemic beliefs, particularly personal justification (which did not have internal consistency high enough to be retained for this current study), as well as their perceptions and endorsements of the investigative practices I measured in this study. Additionally, I will explore science teachers’ epistemic and non-epistemic aims related to their science content and teaching. While the aims in this study did factor into two separate types of aims, all aims overall were endorsed fairly highly (see limitations section above). I will also ask them to re-read the vignettes they completed in the study and ask probing questions regarding their responses.

Finally, as I mentioned in previous sections, I expected to find profiles of beliefs that would be high in EBS and low in EBL and I did not. Instead I found that the relative difference between EBS and EBL was maintained across all three profiles. However, one of the limitations of LPA is that the researcher loses variability by forcing participants into groups. In future
research, I would like to go back to the data and identify cases where there is a misalignment between EBS and EBL and examine these individuals’ relationships to epistemic aims, self-efficacy, ITI, and investigative practices.

As I mentioned in the implications section above, science education in general would benefit from research on developmentally appropriate ways to teach aspects of epistemic cognition such as source verification and criteria for truth. The movement needs to be towards intentionally educating students to be evaluativists. This requires training teachers to be evaluativists as well.

One likely place is in teacher education programs. Science teacher educators have a key opportunity to influence science teachers and their thinking about scientific knowledge. Another place this could start is in post-secondary science classrooms. Pre-service science teachers are required to take a certain number of science content courses. Previous research has shown that the more laboratory experience one has, the more likely they are to have more sophisticated epistemic beliefs about scientific knowledge (Samarapungavan et al., 2006). Encouraging (or requiring) scientific laboratory experience (beyond the traditional co-requisite lab classes that do not function like professional laboratories) could show to pre-service science teachers how science is actually done as opposed to how it is traditionally taught in schools. There are also professional development opportunities for field and/or laboratory experiences for in-service teachers.

Conclusion

This study sought to explore the relationship between two seemingly competing sets of epistemic beliefs and their relationship to science teaching practice. Consistent with prior research and with my own hypothesis, epistemic beliefs in the natural sciences were significantly
different from epistemic beliefs in the learning science. They were not, however, different from each other based on subject-area (i.e., biology, chemistry, physics, Earth science). Furthermore, their factor structure was also slightly different, indicating that participants conceived of the sub-constructs in the two scales differently, particularly regarding their conceptions of certainty and authority as source/expert knowledge.

Latent profile analysis revealed three distinct profiles of participants that were classified as naïve (high scores on EBS and EBL), medium (medium scores of EBS and EBL), and sophisticated (low scores on EBS and EBL). These profiles differentially predicted two different types of science teaching practices, both directly and indirectly. This adds to the body of research on epistemic cognition by emphasizing the importance of person-centered analysis working in partnership with variable-centered analysis, as well as the central role other factors (such as self-efficacy) play in the epistemic cognitive process.
REFERENCES CITED


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APPENDIX A

Background Information and Demographics

1. In total, how many years have you taught?
   a. I am a first year teacher
   b. 1-2
   c. 3-5
   d. 6-10
   e. 11-15
   f. 16 or more

2. In what area(s) are you certified to teach? (Select all that apply)
   a. Elementary Education
   b. Middle Grades – Science
   c. Middle Grades - Math
   d. Secondary – Science
   e. Secondary – Math
   f. Other (please specify)
   g. N/A

3. What grade-level and subject(s) have you taught? (Select all that apply)
   a. High school biology
   b. High school chemistry
   c. High school physics
   d. High school Earth Science
   e. Middle school biology
   f. Middle school chemistry
   g. Middle school physics
   h. Middle school Earth science
   i. Other (please specify)

4. What do you consider to be the primary subject area you teach? If you teach more than one subject, please pick the one with which you most identify.
   a. Biology
   b. Chemistry
   c. Physics
   d. Earth Science

5. How did you obtain your teaching certification?
   a. Through an undergraduate teacher preparation program
   b. Through a post-baccalaureate or Master’s degree program at a university
   c. Through an alternative teacher certification program such as Teach for America (please specify)
   d. I am not certified but I currently teach

6. What was your major in college? (select all that apply)
   a. Education
   b. Biology
   c. Chemistry
   d. Physics
e. Earth Science
f. Other (please specify)

7. How many college-level science courses have you taken?
   a. 0
   b. 1
   c. 2
   d. 3
   e. 4
   f. 5
   g. 6
   h. 7
   i. 8
   j. 9
   k. 10+

8. How many college-level education courses have you taken?
   a. 0
   b. 1
   c. 2
   d. 3
   e. 4
   f. 5
   g. 6
   h. 7
   i. 8
   j. 9
   k. 10+

9. How many graduate-level science courses have you taken?
   a. 0
   b. 1
   c. 2
   d. 3
   e. 4
   f. 5
   g. 6
   h. 7
   i. 8
   j. 9
   k. 10+

10. How many graduate-level education courses have you taken?
    a. 0
    b. 1
    c. 2
    d. 3
    e. 4
    f. 5
    g. 6
11. Rate your level of comfort in teaching [biology/chemistry/physics/earth science] content.
   a. 1 – Not at all comfortable
   b. 2
   c. 3 – Comfortable
   d. 4
   e. 5 – Extremely comfortable
12. What type(s) of laboratory research experience have you had? (Select all that apply)
   a. Undergraduate lab classes
   b. Graduate-level lab classes
   c. Professional experience in a research lab
   d. Other, please explain:
13. Please describe your laboratory research experience including your
    activities/responsibilities in the lab, as well as how long you were there?
14. What type(s) of professional development (PD) have you had? (Select all that apply)
   a. Professional networking groups
   b. Single-day workshops
   c. Multi-day workshops
   d. Online PD support
   e. Other, please explain:
15. How frequently do you engage in professional development?
   a. Weekly
   b. Monthly
   c. A few times a year
   d. Annually
   e. Other, please explain:
16. The school where my community is located can be best described as:
   a. Rural
   b. Suburban
   c. Urban
17. What is the highest level of education you have attained?
   a. Bachelor’s
   b. Master’s
   c. EdS
   d. EdD
   e. PhD
   f. Other (please specify)
18. If you have a post-secondary degree, what is it in? (Select all that apply)
   a. Education
   b. Biology
   c. Chemistry
   d. Physics
19. In what year were you born?
20. What is your sex?
   a. Male
   b. Female
   c. Other
21. Which of the following best describes your ethnic background?
   a. White
   b. Black or African-American
   c. Hispanic or Latino
   d. Asian/Asian-American
   e. Native American/American Indian
   f. Other
APPENDIX B

(Subject-Specific) Discipline-Focused Epistemological Beliefs Questionnaire
(adapted from Hofer, 2000)

[Subjects include biology, chemistry, physics and earth science and will pre-populate depending on respondents’ answer to Q4 in the Background Questionnaire.]

1 – Strongly disagree…5 – Strongly agree

Now I will ask you a set of questions about your beliefs about knowledge in [science subject].

1. Answers to question about [topic] change as experts gather more information.*
2. All experts in [topic] understand the field in the same way.
3. Truths about [topic] are unchanging.
4. In [topic], most work has only one right answer.
5. Principles of [topic] are unchanging.
6. All experts in [topic] would probably come up with the same answers to questions in this field.
7. In [topic], it is good to question the ideas presented.*
8. Most of what is true in the field of [topic] is already known.
9. First-hand experience is the best way of knowing something about [topic].
10. I am more likely to accept the ideas of someone with firsthand experience than the ideas of researchers who study [topic].
11. Correct answers about [topic] are more a matter of opinion than fact.
12. There is really no way to determine whether someone has the right answer to problems in [topic].
13. Sometimes you just have to accept answers from the experts in [topic], even if you don’t understand them.
14. If you read something about [topic] in a textbook, you can be sure it’s true.
15. If my personal experience with [topic] conflicts with ideas in the textbook, the book is probably right.
16. I am most confident that I know something about [topic] when I know what the experts think.
17. Experts in [topic] can ultimately get to the truth.
18. If scholars and scientists try hard enough, they can find the answers to almost anything.
(Subject-Specific) Discipline-Focused Epistemological Beliefs Questionnaire
(adapted from Hofer, 2000)

[All teachers will answer these questions about how students learn science.]
1 – Strongly disagree…5 – Strongly agree

Now I will ask you a series about your beliefs about the science of how students learn.

1. Answers to question about how students learn science change as experts gather more information.*
2. All experts in student learning understand the field in the same way.
3. Truths about student learning are unchanging.
4. In student learning, most problems have only one right answer.
5. Principles of student learning are unchanging.
6. All experts in student learning would probably come up with the same answers to questions in this field.
7. In student learning, it is good to question the ideas presented.*
8. Most of what is true in the field of student learning is already known.
9. First-hand experience is the best way of knowing something about how students learn.
10. I am more likely to accept the ideas of someone with firsthand experience than the ideas of researchers who study how students learn.
11. Correct answers about student learning are more a matter of opinion than fact.
12. There is really no way to determine whether someone has the right answer to problems in student learning.
13. Sometimes you just have to accept answers from the experts in student learning, even if you don’t understand them.
14. If you read something about how students learn in a textbook, you can be sure it’s true.
15. If my personal experience with how students learn conflicts with ideas in the textbook, the book is probably right.
16. I am most confident that I know something about how students learn when I know what the experts think.
17. Experts in student learning can ultimately get to the truth.
18. If scholars and scientists try hard enough, they can find the answers to almost anything.

Certainty of Science

19. With which of the following statements do you most agree?
   a. In science, knowledge is absolute.
   b. In science, knowledge is uncertain.
   c. In science, some knowledge is absolute and some is uncertain.

20. Please give an example of scientific knowledge that is absolute.

21. Please give an example of scientific knowledge that is uncertain.
APPENDIX C

Epistemic Aims Questionnaire

1. When teaching [subject], what aims or goals do you set for your students?

When teaching [subject], I aim for my students to…

1 – Not at all, 2 – To a small extent, 3 – To a moderate extent, 4 – To a large extent, 5 – To a very large extent

1. Learn specific facts about [subject].
2. Understand how [subject] is related to other science topics (e.g., biology, chemistry, physics, earth science).
3. Understand how [subject] is related to other school subjects.
4. Explain how [subject] is related to the real-world.
5. Explain how [subject] is related to their own lives.
6. Explain why and how certain phenomenon in [subject] occur (e.g., DNA replication, population growth; chemical reactions, phase changes; perpetual motion, thermodynamics; tides, earthquakes)
7. Challenge students’ alternative conceptions about [subject].
8. Correct false prior knowledge about [subject].
9. Evaluate [biological/chemical/physics/earth science] models (e.g., natural selection, photosynthesis; atomic models, particle model of matter; solar systems, light; climate change, planetary movement)
10. Question or challenge ideas and concepts I teach them about [subject]

Please rank your top 5 aims for your students when teaching [subject]. (Write 1 for the most important, 2 for the second most important, etc.)

___ Learn specific facts about [subject].
___ Understand how [subject] is related to other science topics (e.g., biology, chemistry, physics, earth science).
___ Understand how [subject] is related to other school subjects.
___ Explain how [subject] is related to the real-world.
___ Explain how [subject] is related to their own lives.
___ Explain why and how certain phenomenon in [subject] occur (e.g., DNA replication, population growth; chemical reactions, phase changes; perpetual motion, thermodynamics; tides, earthquakes)
___ Challenge students’ alternative conceptions about [subject].
___ Correct false prior knowledge about [subject].
___ Evaluate [biological/chemical/physics/earth science] models (e.g., natural selection, photosynthesis; atomic models, particle model of matter; solar systems, light; climate change, planetary movement)
___ Question or challenge ideas and concepts I teach them about [subject]
APPENDIX D

Beliefs about Student Learning in Science

Implicit Theories of Intelligence
(adapted from Dweck, 1999 and Dai & Cromley, 2014b)

1 – Strongly disagree...5 – Strongly agree
1. My students have a certain amount of ability in learning [subject], and they can’t really do much about it.
2. The harder my students work at learning about [topic], the more they can improve their ability in [subject].
3. My students’ ability in learning about [subject] is something that they can’t change very much.
4. My students can considerably change even their basic level of ability in learning about [subject].
5. My students can learn new things, but they can’t really change their basic ability level in learning about [subject].
6. My students can always substantially change their level of ability in learning about [subject].
7. Now matter how much ability my students have in learning about [subject], they can always change it quite a bit.
8. If my students work hard, they can improve their basic ability in learning about [subject].
APPENDIX E

Science Teaching Practices Questionnaire

The next series of questions will ask you about your teaching classes in the science classroom.

1. How would you teach a typical [subject] lesson? Please provide specific examples of how you spend class time, types of assignments students do, and types and frequency of assessments.

   Investigative Teaching Practices
   (adapted from Supovitz & Turner, 2000)

   1 – Never; 2 – Once or twice a semester; 3 – Once or twice a month; 4 – Once or twice a week; 5 – Almost daily

Teachers’ Investigative Practices
How frequently do students in your class:
   1. Make formal presentations to class
   2. Engage in hands-on science activities
   3. Design or implement their own investigations
   4. Work on models or simulations
   5. Work on extended science investigations or projects (a week or more in duration)
   6. Participate in field work
   7. Write reflections in a notebook or journal
   8. Work on a portfolio

Teachers’ Classroom Culture of Investigation
How often do you:
   1. Arrange seating to facilitate student discussion
   2. Use open-ended questions
   3. Require students to supply evidence to support their claims
   4. Encourage students to explain concept to one another
   5. Encourage students to consider alternative explanations
   6. Have students participate in discussion with the students to further science understanding
   7. Have students work in cooperative learning groups
   8. Have students share ideas or solve problems with each other in small groups

Approximately what percentage of class time do you spent on the following activities when teaching [subject]? (Must add up to 100.)
   Lecture _____
   Assessment _____
   Lab work _____
   Large class discussion _____
   Small group discussion/work _____
   Other (please explain): _____
APPENDIX F

Self-Efficacy for Science Teaching
(adapted from Woolfolk-Hoy, Hoy, and Davis, 2009)

1 – Nothing…9 – A Great Deal

1. To what extent can you use a variety of assessment strategies when teaching [subject]?
2. To what extent can you provide an alternative explanation or example when students are confused about [subject]?
3. To what extent can you craft good questions about [subject] for your students?
4. How well can you implement alternative strategies in your classroom?
5. How much can you do to control disruptive behavior in the classroom?
6. How much can you do to get children to follow classroom rules?
7. How much can you do to calm a student who is disruptive or noisy?
8. How well can you establish a classroom management system with each group of students?
9. How much can you do to get students to believe they can do well in [subject]?
10. How much can you do to help your students value learning about [subject]?
11. How much can you do to motivate students who show low interest in [subject]?
12. How much can you assist families in helping their children do well in [subject]?
APPENDIX G

Teacher Vignettes

*Biology*

*Mr. Rodriguez*

Mr. Rodriguez is teaching a unit on energy in a biology class. As students enter his classroom, he greets each one by name and asks how their day is going. Mr. Rodriguez’s students like him and enjoy his class. As everyone gets settled, he begins class by telling students they are going to take a pop quiz. Many of the students grumble. “I know, I know,” says Mr. Rodriguez, “but it’s really important that you read the textbook chapters I assign to you. I need to make sure you guys are getting this stuff so you can do well on the test.” Mr. Rodriguez believes that the important knowledge students need to know can be found in the textbook and in his lectures; he assures his students that this is the key to success in his class.

“You should have no problem answering the questions on the pop-quiz if you were paying attention in class yesterday and read the textbook chapter that was assigned for homework last night.” As he collects the quizzes, he says, “If more than half the class fails the quiz then I won’t count it, but the next one I will.” He then hands the quizzes back to the students, instructing them to grade each other’s work. Mr. Rodriguez asks a student to read each question aloud and calls on another student to attempt a short answer. Mr. Rodriguez wants his students to succeed and feels that accuracy is very important. Therefore, when a student provides an incorrect answer, Mr. Rodriguez says the correct answer and the students copy it down. He slows down and repeats his answers verbatim for more complicated questions, because he cares about his students’ learning and success.

Mr. Rodriguez then begins his PowerPoint presentation on the day’s topic: photosynthesis. He thinks foundational knowledge is crucial to students’ understanding of the topic. Therefore, he reads through and elaborates on an outline of facts from the textbook chapter, while the students take notes. “Alright, we have a lot of content to cover today so let’s get started. Photosynthesis is the chemical process by which sunlight is converted into sugars. Stage one of photosynthesis consists of the light-dependent reactions. Who can tell me what is created in this stage?” He pauses for a moment. “Oxygen, ATP, and NADPH. This is important because ATP is used in the production of glucose, the main purpose of photosynthesis.” Mr. Rodriguez continues with his lecture.

After completing his lecture, he hands out study guides to help his students prepare for their upcoming test. He instructs his students to spend the remainder of the class period completing questions 1-30 in the study guide. These questions consist of filling in definitions and short open-ended answer questions that request students to search factual information in the textbook and in-class lectures that Mr. Rodriguez plans to include on the test.
Ms. Brown

Ms. Brown is teaching a unit on energy in a biology class. She greets her students by name as they enter the classroom and asks how their day is going. Ms. Brown’s students like her and enjoy her class. Ms. Brown strives to help her students connect class material to previously covered topics. She begins with a brief review of previously covered topics and connects them to today’s topic: photosynthesis. She asks students what questions they had from last night’s reading. Ms. Brown believes that students learn knowledge through interactions, so she facilitates students’ responses to each other’s questions, and encourages students to collaborate in thinking about answers.

Ms. Brown strives to challenge students’ misconceptions about biology and to help them think critically about the material. When a student answers that photosynthesis is the process by which green plants obtain food from the sun in order to live, she invites other students to respond, and eventually summarizes the ideas they have raised by saying that “photosynthesis occurs in plants of all different colors, not just green ones. And it is the plant that is using energy from the sun to carry out photosynthesis and respiration, which produces the plant’s ‘food’ or energy.”

She continues by saying to students: “These are all great points. You know, there are still some mechanisms of photosynthesis that scientists do not understand. There was a time not that long ago, where they knew plants converted chemical energy from the sun into glucose but had no idea how. Science is always a work in progress.”

One of Ms. Brown’s aims for her students is to understand how biological processes function in the real world. “Now that you’ve read about photosynthesis, let’s look at it in context. In your groups, apply what you know about photosynthesis to the problem of global warming. How are the two processes related? How might photosynthesis be used to address global warming?” The students work in small groups, while Ms. Brown circulates around the room, joins each group for a time, offering feedback and answering questions.

After completing the activity, one student from each group reports their ideas to the entire class. Ms. Brown prompts each group to explain how they came to their conclusion about the relationship between photosynthesis and global warming, and to provide a justification for their answer. “There are no answers in the back of your textbook for this problem,” she says. “There is no single correct answer. Justify your solutions with logic and what you know about photosynthesis.” She encourages the other groups to think critically about each group’s suggestions.
Mr. Rodriguez is teaching a unit on energy in a chemistry class. As students enter his classroom, he greets each one by name and asks how their day is going. Mr. Rodriguez’s students like him and enjoy his class. As everyone gets settled, he begins class by telling students they are going to take a pop quiz. Many of the students grumble. “I know, I know,” says Mr. Rodriguez, “but it’s really important that you read the textbook chapters I assign to you. I need to make sure you guys are getting this stuff so you can do well on the test.” Mr. Rodriguez believes that the important knowledge students need to know can be found in the textbook and in his lectures; he assures his students that this is the key to success in his class.

“You should have no problem answering the questions on the pop-quiz if you were paying attention in class yesterday and read the textbook chapter that was assigned for homework last night.” As he collects the quizzes, he says, “If more than half the class fails the quiz then I won’t count it, but the next one I will.” He then hands the quizzes back to the students, instructing them to grade each other’s work. Mr. Rodriguez asks a student to read each question aloud and calls on another student to attempt a short answer. Mr. Rodriguez wants his students to succeed and feels that accuracy is very important. Therefore, when a student provides an incorrect answer, Mr. Rodriguez says the correct answer and the students copy it down. He slows down and repeats his answers verbatim for more complicated questions, because he cares about his students’ learning and success.

Mr. Rodriguez then begins his PowerPoint presentation on the day’s topic: chemical bonds. He thinks foundational knowledge is crucial to students’ understanding of the topic. Therefore, he reads through and elaborates on an outline of facts from the textbook chapter, while the students take notes. “Alright, we have a lot of content to cover today so let’s get started. Chemical bonds contain energy, however, energy must be added to the system to get an output of energy. But where does the energy for breaking bonds come from?” He pauses for a moment. “It comes from the formation of stronger bonds in the newly formed molecules. The larger the difference in bond energies between the product and the reactant, the more energy is available. Some examples of chemical bonds include the formation of oxygen and glucose in photosynthesis, and hydrogen fuel.” Mr. Rodriguez continues with his lecture.

After completing his lecture, he hands out study guides to help his students prepare for their upcoming test. He instructs his students to spend the remainder of the class period completing questions 1-30 in the study guide. These questions consist of filling in definitions and short open-ended answer questions that request students to search factual information in the textbook and in-class lectures that Mr. Rodriguez plans to include on the test.
Ms. Brown

Ms. Brown is teaching a unit on energy in a chemistry class. She greets her students by name as they enter the classroom and asks how their day is going. Ms. Brown’s students like her and enjoy her class. Ms. Brown strives to help her students connect class material to previously covered topics. She begins with a brief review of previously covered topics and connects them to today’s topic: chemical bonds. She asks students what questions they had from last night’s reading. Ms. Brown believes that students learn knowledge through interactions, so she facilitates students’ responses to each others’ questions, and encourages students to collaborate in thinking about answers.

Ms. Brown strives to challenge students’ misconceptions about chemistry and to help them think critically about the material. When a student answers that energy is stored in chemical bonds, she invites other students to respond, and eventually summarizes the ideas they have raised by saying that “energy comes the formation of new bonds, not breaking existing bonds.”

She continues by saying to students: “These are all great points. You know, there are still some things about chemical bonds that scientists do not yet understand. In fact, scientists recently discovered a brand new type of chemical bond found only in dwarf stars. Science is always a work in progress.”

One of Ms. Brown’s aims for her students is to understand how chemical processes function in the real world. “Now that you’ve read about chemical bonds, let’s apply it in context. In your small groups, apply what you know about chemical bonds and think of a few real-life example of chemical bonds. What are the products and reactants? Why type of bond is it? How is energy created in the formation of these bonds?” The students work in small groups while Ms. Brown circulates around the room, joins each group for a time, offering feedback and answering questions.

After completing the activity, one student from each group reports their ideas to the entire class. Ms. Brown prompts each group to explain how they came to their conclusions about real-life examples of chemical bonds, and to provide justification for their answer. “There are no answers in the back of your textbook for this,” she says. “There is no single correct answer. Justify your solutions with logic and what you know about chemical bonds.” She encourages the other groups to think critically about each group’s suggestions.
Mr. Rodriguez is teaching a unit on energy in a physics class. As students enter his classroom, he greets each one by name and asks how their day is going. Mr. Rodriguez’s students like him and enjoy his class. As everyone gets settled, he begins class by telling students they are going to take a pop quiz. Many of the students grumble. “I know, I know,” says Mr. Rodriguez, “but it’s really important that you read the textbook chapters I assign to you. I need to make sure you guys are getting this stuff so you can do well on the test.” Mr. Rodriguez believes that the important knowledge students need to know can be found in the textbook and in his lectures; he assures his students that this is the key to success in his class.

“You should have no problem answering the questions on the pop-quiz if you were paying attention in class yesterday and read the textbook chapter that was assigned for homework last night.” As he collects the quizzes, he says, “If more than half the class fails the quiz then I won’t count it, but the next one I will.” He then hands the quizzes back to the students, instructing them to grade each other’s work. Mr. Rodriguez asks a student to read each question aloud and calls on another student to attempt a short answer. Mr. Rodriguez wants his students to succeed and feels that accuracy is very important. Therefore, when a student provides an incorrect answer, Mr. Rodriguez says the correct answer and the students copy it down. He slows down and repeats his answers verbatim for more complicated questions, because he cares about his students’ learning and success.

Mr. Rodriguez then begins his PowerPoint presentation on the day’s topic: thermodynamics. He thinks foundational knowledge is crucial to students’ understanding of the topic. Therefore, he reads through and elaborates on an outline of facts from the textbook chapter, while the students take notes. “Alright, we have a lot of content to cover today so let’s get started. Energy, as you’ll recall, is the ability to do work. Today we’re going to be talking about the First Law of Thermodynamics. Does anyone know what this law says?” He pauses for a moment. “It states that energy cannot be created or destroyed, it is transferred or changes form. This is important for all types of thermodynamic systems from car engines to environmental systems to solar systems.” Mr. Rodriguez continues with his lecture.

After completing his lecture, he hands out study guides to help his students prepare for their upcoming test. He instructs his students to spend the remainder of the class period completing questions 1-30 in the study guide. These questions consist of filling in definitions and short open-ended answer questions that request students to search factual information in the textbook and in-class lectures that Mr. Rodriguez plans to include on the test.
Ms. Brown

Ms. Brown is teaching a unit on energy in a physics class. She greets her students by name as they enter the classroom and asks how their day is going. Ms. Brown’s students like her and enjoy her class. Ms. Brown strives to help her students connect class material to previously covered topics. She begins with a brief review of previously covered topics and connects them to today’s topic: thermodynamics. She asks students what questions they had from last night’s reading. Ms. Brown believes that students learn knowledge through interactions, so she facilitates students’ responses to each others’ questions, and encourages students to collaborate in thinking about answers.

Ms. Brown strives to challenge students’ misconceptions about physics and to help them think critically about the material. When a student answers that energy in a system is lost due to friction, she invites other students to respond, and eventually summarizes the ideas they have raised by saying that “energy is converted, often to heat, due to friction, but it is never lost from the system.”

She continues by saying to students: “These are all great points. You know, there are still some things about thermodynamics that scientists do not yet understand. In fact, scientists recently discovered that certain particles, under specific conditions, actually violate the Second Law of Thermodynamics. Science is always a work in progress.”

One of Ms. Brown’s aims for her students is to understand how physics functions in the real world. “Now that you’ve read about thermodynamics, let’s look at it in context. In your groups, apply what you know about thermodynamics to the problem of global warming. How are the two processes related? What laws and mechanisms of thermodynamics are at work here?” The students work in small groups, while Ms. Brown circulates around the room, joins each group for a time, offering feedback and answering questions.

After completing the activity, one student from each group reports their ideas to the entire class. Ms. Brown prompts each group to explain how they came to their conclusion about the relationship between thermodynamics and global warming, and to provide a justification for their answer. “There are no answers in the back of your textbook for this,” she says. “There is no single correct answer. Justify your solutions with logic and what you know about thermodynamics.” She encourages the other groups to think critically about each group’s suggestions.
Mr. Rodriguez is teaching a unit on energy in an Earth science class. As students enter his classroom, he greets each one by name and asks how their day is going. Mr. Rodriguez’s students like him and enjoy his class. As everyone gets settled, he begins class by telling students they are going to take a pop quiz. Many of the students grumble. “I know, I know,” says Mr. Rodriguez, “but it’s really important that you read the textbook chapters I assign to you. I need to make sure you guys are getting this stuff so you can do well on the test.” Mr. Rodriguez believes that the important knowledge students need to know can be found in the textbook and in his lectures; he assures his students that this is the key to success in his class.

“You should have no problem answering the questions on the pop-quiz if you were paying attention in class yesterday and read the textbook chapter that was assigned for homework last night.” As he collects the quizzes, he says, “If more than half the class fails the quiz then I won’t count it, but the next one I will.” He then hands the quizzes back to the students, instructing them to grade each other’s work. Mr. Rodriguez asks a student to read each question aloud and calls on another student to attempt a short answer. Mr. Rodriguez wants his students to succeed and feels that accuracy is very important. Therefore, when a student provides an incorrect answer, Mr. Rodriguez says the correct answer and the students copy it down. He slows down and repeats his answers verbatim for more complicated questions, because he cares about his students’ learning and success.

Mr. Rodriguez then begins his PowerPoint presentation on the day’s topic: solar energy. He thinks foundational knowledge is crucial to students’ understanding of the topic. Therefore, he reads through and elaborates on an outline of facts from the textbook chapter, while the students take notes. “Alright, we have a lot of content to cover today so let’s get started. Photons from the sun hit silicon atoms inside photovoltaic cells and force one of their electrons out of the silicon’s outermost orbit. All of these free electrons are attracted to a magnetic strip in the solar panel, which leads into the power grid of your house to be used as energy. So why isn’t solar energy more common?” He pauses for a moment. “Well for one, it’s not very efficient. A lot of solar energy is lost as heat. This is important because it is one of the barriers to wider usage of solar energy.” Mr. Rodriguez continues with his lecture.

After completing his lecture, he hands out study guides to help his students prepare for their upcoming test. He instructs his students to spend the remainder of the class period completing questions 1-30 in the study guide. These questions consist of filling in definitions and short open-ended answer questions that request students to search factual information in the textbook and in-class lectures that Mr. Rodriguez plans to include on the test.
Ms. Brown is teaching a unit on energy in an Earth science class. She greets her students by name as they enter the classroom and asks how their day is going. Ms. Brown’s students like her and enjoy her class. Ms. Brown strives to help her students connect class material to previously covered topics. She begins with a brief review of previously covered topics and connects them to today’s topic: solar energy. She asks students what questions they had from last night’s reading. Ms. Brown believes that students learn knowledge through interactions, so she facilitates students’ responses to each others’ questions, and encourages students to collaborate in thinking about answers.

Ms. Brown strives to challenge students’ misconceptions about Earth science and to help them think critically about the material. When a student answers that solar power can only be created when it is warm and sunny, she invites other students to respond, and eventually summarizes the ideas they have raised by saying that “ultraviolet light has the highest potential for creating solar power and solar panels can use ultraviolet light regardless of temperature and amount of sunlight.”

She continues by saying to students: “These are all great points. You know, there are still some things about solar energy that scientists do not yet understand. In fact, scientists just created a new type of photovoltaic cell that can capture the Sun’s heat energy that had previously been released into the atmosphere making solar energy very inefficient.”

One of Ms. Brown’s aims for her students is to understand how solar energy functions in the real world. “Now that you’ve read about solar energy, let’s look at it in context. The city council of Tucson, Arizona wants to retrofit an old building with solar panels. A traditional solar panel array big enough to supply the building’s energy needs will not fit on the roof. How would you overcome this problem and still produce the necessary power output?” The students work in small groups, while Ms. Brown circulates around the room, joins each group for a time, offering feedback and answering questions.

After completing the activity, one student from each group reports their ideas to the entire class. Ms. Brown prompts each group to explain how they came to their conclusion about the best way to provide solar energy to an old building, and to provide a justification for their answer. “There are no answers in the back of your textbook for this,” she says. “There is no single correct answer. Justify your solutions with logic and what you know about solar energy.” She encourages the other groups to think critically about each group’s suggestions.
How would you rate the overall quality of Mr. Rodriguez’s lesson?
1 2 3 4 5
Low quality High quality

Please explain:

With which aspects of Mr. Rodriguez’s teaching do you most identify? Why? Please provide specific examples.

With which aspects of Mr. Rodriguez’s teaching do you least identify? Why? Please provide specific examples.

How would you rate the overall quality of Ms. Brown’s lesson?
1 2 3 4 5
Low quality High quality

Please explain:

With which aspects of Ms. Brown’s teaching do you most identify? Why? Please provide specific examples.

With which aspects of Ms. Brown’s teaching do you least identify? Why? Please provide specific examples.

Based on the above vignettes, are you more like Mr. Rodriguez or Ms. Brown?
1 2 3 4 5 6 7
Mr. Rodriguez Ms. Brown

Please explain:
### APPENDIX H

Supplementary Table

**Table 12**

*Item-Level Descriptive Statistics of Epistemic Beliefs, Epistemic Aims,*

<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Epistemic Beliefs</td>
<td>Answers to questions about [subject] change as experts gather more information. (R)</td>
<td>521</td>
<td>1</td>
<td>5</td>
<td>4.12</td>
<td>.82</td>
<td>-1.06</td>
<td>1.56</td>
</tr>
<tr>
<td></td>
<td>All experts in [subject] understand the field in the same way.</td>
<td>520</td>
<td>1</td>
<td>5</td>
<td>2.35</td>
<td>1.04</td>
<td>.77</td>
<td>-.06</td>
</tr>
<tr>
<td></td>
<td>Truths about [subject] are unchanging.</td>
<td>521</td>
<td>1</td>
<td>5</td>
<td>2.54</td>
<td>1.11</td>
<td>.48</td>
<td>-.67</td>
</tr>
<tr>
<td></td>
<td>In [subject], most work has only one right answer</td>
<td>521</td>
<td>1</td>
<td>5</td>
<td>2.82</td>
<td>1.09</td>
<td>.05</td>
<td>-.95</td>
</tr>
<tr>
<td></td>
<td>Principles of [subject] are unchanging.</td>
<td>522</td>
<td>1</td>
<td>5</td>
<td>2.60</td>
<td>1.12</td>
<td>.41</td>
<td>-.78</td>
</tr>
<tr>
<td></td>
<td>All experts in [subject] would probably come up with the same answer to questions in the field.</td>
<td>520</td>
<td>1</td>
<td>5</td>
<td>2.35</td>
<td>1.04</td>
<td>.20</td>
<td>-.90</td>
</tr>
<tr>
<td></td>
<td>In [subject], it is good to question the ideas presented. (R)</td>
<td>520</td>
<td>1</td>
<td>5</td>
<td>1.93</td>
<td>.86</td>
<td>1.22</td>
<td>2.01</td>
</tr>
<tr>
<td></td>
<td>Most of what is true in the field of [subject] is already known.</td>
<td>521</td>
<td>1</td>
<td>5</td>
<td>2.55</td>
<td>1.01</td>
<td>.31</td>
<td>-.87</td>
</tr>
<tr>
<td></td>
<td>First-hand experience is the best way of knowing something about [subject].</td>
<td>522</td>
<td>1</td>
<td>5</td>
<td>3.58</td>
<td>.98</td>
<td>-.45</td>
<td>-.45</td>
</tr>
<tr>
<td></td>
<td>I am more likely to accept the ideas of someone with firsthand experience in [subject] than the ideas of researchers in the field.</td>
<td>520</td>
<td>1</td>
<td>5</td>
<td>3.00</td>
<td>1.01</td>
<td>-.06</td>
<td>-.53</td>
</tr>
<tr>
<td></td>
<td>Correct answers about [subject] are more a matter of opinion than fact.</td>
<td>522</td>
<td>1</td>
<td>5</td>
<td>2.14</td>
<td>.95</td>
<td>.86</td>
<td>.45</td>
</tr>
<tr>
<td></td>
<td>There is really no way to determine whether someone has the right answers to problems in [subject].</td>
<td>519</td>
<td>1</td>
<td>5</td>
<td>2.35</td>
<td>.94</td>
<td>.71</td>
<td>.05</td>
</tr>
</tbody>
</table>
Sometimes you just have to accept answers from the experts in [subject] even if you don’t understand them.

If you read something about [subject] in a textbook, you can be sure it’s true.

If my personal experience with [subject] conflicts with ideas in the textbook, the book is probably right.

I am most confident that I know something about [subject] when I know what the experts think.

Experts in [subject] can ultimately get to the truth.

If scholars and scientists try hard enough they can find the answers to almost anything in [subject].

Epistemic Beliefs
– Learning Sciences

Answers to questions about how students learn change as experts gather more information. (R)

All experts in how students learn understand the field in the same way.

Truths about how students learn are unchanging.

Most problems regarding how students learn have only one right answer.

Principles about how students learn are unchanging.

All experts in how students learn would probably come up with the same answer to questions in the field.

It is good to question the ideas presented about how students learn. (R)
Most of what is true about how students learn is already known.  
First-hand experience is the best way of knowing something about how students learn.  
I am more likely to accept the ideas of someone with firsthand experience than the ideas of researchers who study how students learn.  
Correct answers about how students learn are more a matter of opinion than fact.  
There is really no way to determine whether someone has the right answer about how students learn.  
Sometimes you just have to accept answers about how students learn from the experts even if you don’t understand them.  
If you read something about how students learn in a textbook, you can be sure it’s true.  
If my personal experience with how students learn conflicts with ideas in the textbook, the book is probably right.  
I am most confident that I know something about how students learn when I know what the experts think.  
Experts can ultimately get to the truth about how students learn.  
If scholars and scientists try hard enough they can find the answers to almost anything in student learning.

Epistemic Aims –
“When teaching [subject], I aim for my students to...”
Learn specific facts about [subject].
Understand how [subject] is related to other science topics (e.g., biology, chemistry, physics, Earth science)
Understand how [subject] is related to other school subjects.
Explain how [subject] is related to the real-world.
Explain how [subject] is related to their own lives.
Explain why and how certain phenomenon in [subject] occur (e.g., DNA replication, population growth).
Challenge students’ alternative conceptions about [subject].
Correct prior false knowledge about [subject].
Evaluate [subject] models (e.g., natural selection, photosynthesis).
Question ideas and concepts I teach them about [subject].

Table 13
Item-Level Descriptive Statistics of Self-efficacy, Theories of Intelligence, and Teaching Practices

<table>
<thead>
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<th></th>
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</thead>
<tbody>
<tr>
<td>Self-Efficacy “How much can do you to...”</td>
<td>craft good questions about [subject] for students?</td>
<td>491</td>
<td>2</td>
<td>9</td>
<td>7.18</td>
<td>1.45</td>
<td>-.79</td>
<td>.77</td>
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<tr>
<td></td>
<td>implement a variety of assessment strategies about [subject]?</td>
<td>492</td>
<td>1</td>
<td>9</td>
<td>7.04</td>
<td>1.53</td>
<td>-.59</td>
<td>.23</td>
</tr>
<tr>
<td></td>
<td>provide an alternate explanation when students are confused about [subject]?</td>
<td>492</td>
<td>2</td>
<td>9</td>
<td>7.10</td>
<td>1.5</td>
<td>-.69</td>
<td>.14</td>
</tr>
<tr>
<td></td>
<td>implement alternative strategies in your classroom when teaching about [subject]?</td>
<td>492</td>
<td>1</td>
<td>9</td>
<td>7.00</td>
<td>1.60</td>
<td>-.72</td>
<td>.29</td>
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151
**Implicit Theories of Intelligence**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Type of Question</th>
<th>Participants</th>
<th>M</th>
<th>SD</th>
<th>Effect Size</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>489</td>
<td>Motivate students who show low interest in [subject]?</td>
<td>1</td>
<td>9</td>
<td>6.74</td>
<td>1.65</td>
<td>-.56</td>
</tr>
<tr>
<td>492</td>
<td>Get students to believe they can do well in [subject]?</td>
<td>1</td>
<td>9</td>
<td>7.04</td>
<td>1.48</td>
<td>-.67</td>
</tr>
<tr>
<td>492</td>
<td>Help students value learning about [subject]?</td>
<td>1</td>
<td>9</td>
<td>7.01</td>
<td>1.48</td>
<td>-.67</td>
</tr>
<tr>
<td>492</td>
<td>Assist families in helping their children learn about [subject]?</td>
<td>1</td>
<td>9</td>
<td>6.24</td>
<td>1.81</td>
<td>-.47</td>
</tr>
<tr>
<td>483</td>
<td>My students have a certain amount of ability in learning [subject], and they can’t really do much about it.</td>
<td>1</td>
<td>5</td>
<td>2.02</td>
<td>.98</td>
<td>1.03</td>
</tr>
<tr>
<td>484</td>
<td>The harder my students work at learning about [subject], the more they can improve their ability in [subject].</td>
<td>1</td>
<td>5</td>
<td>4.32</td>
<td>.72</td>
<td>-1.01</td>
</tr>
<tr>
<td>484</td>
<td>My students' ability in learning about [subject] is something that they can't change very much.</td>
<td>1</td>
<td>5</td>
<td>1.98</td>
<td>.92</td>
<td>1.06</td>
</tr>
<tr>
<td>482</td>
<td>My students can considerably change even their basic level of ability in learning about [subject].</td>
<td>1</td>
<td>5</td>
<td>4.16</td>
<td>.75</td>
<td>-.93</td>
</tr>
<tr>
<td>483</td>
<td>My students can learn new things, but they can't really change their basic ability level in learning about [subject].</td>
<td>1</td>
<td>5</td>
<td>2.14</td>
<td>.98</td>
<td>.89</td>
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<tr>
<td>484</td>
<td>My students can always substantially change their level of ability in learning about [subject].</td>
<td>1</td>
<td>5</td>
<td>4.10</td>
<td>.76</td>
<td>-.71</td>
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<td>483</td>
<td>No matter how much ability my students have in learning about [subject], they can always change it quite a bit.</td>
<td>1</td>
<td>5</td>
<td>3.98</td>
<td>.78</td>
<td>-.74</td>
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<tr>
<td>484</td>
<td>If my students work hard, they can improve their basic ability in learning about [subject].</td>
<td>1</td>
<td>5</td>
<td>4.36</td>
<td>.73</td>
<td>-1.15</td>
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Investigative Teaching Practices

"How frequently do students in your class..."

<table>
<thead>
<tr>
<th>Activity</th>
<th>N</th>
<th>Range</th>
<th>Mean</th>
<th>SD</th>
<th>Skewness</th>
<th>Kurtosis</th>
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<tbody>
<tr>
<td>Make formal presentations to class</td>
<td>487</td>
<td>1-5</td>
<td>2.90</td>
<td>1.15</td>
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<td>-.80</td>
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<td>Engage in hands-on science activities</td>
<td>487</td>
<td>1-5</td>
<td>3.87</td>
<td>.85</td>
<td>-.57</td>
<td>.33</td>
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<tr>
<td>Design or implement their own investigations</td>
<td>485</td>
<td>1-5</td>
<td>3.15</td>
<td>1.00</td>
<td>-.00</td>
<td>-.57</td>
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<td>Work on models or simulations</td>
<td>483</td>
<td>1-5</td>
<td>3.35</td>
<td>.93</td>
<td>-.21</td>
<td>-.19</td>
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<tr>
<td>Work on extended science investigations or projects (a week or more in duration)</td>
<td>486</td>
<td>1-5</td>
<td>2.65</td>
<td>.99</td>
<td>.74</td>
<td>-.07</td>
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<td>Participate in field work</td>
<td>483</td>
<td>1-5</td>
<td>2.29</td>
<td>1.09</td>
<td>.56</td>
<td>-.45</td>
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<tr>
<td>Write reflections in a notebook or journal</td>
<td>485</td>
<td>1-5</td>
<td>3.28</td>
<td>1.45</td>
<td>-.39</td>
<td>-1.21</td>
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<td>Work on a portfolio</td>
<td>484</td>
<td>1-5</td>
<td>2.40</td>
<td>1.31</td>
<td>.45</td>
<td>-1.04</td>
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Investigative culture

"How often do you..."

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<th>N</th>
<th>Range</th>
<th>Mean</th>
<th>SD</th>
<th>Skewness</th>
<th>Kurtosis</th>
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</thead>
<tbody>
<tr>
<td>Arrange seating to facilitate student discussion</td>
<td>486</td>
<td>1-5</td>
<td>3.39</td>
<td>1.33</td>
<td>-.36</td>
<td>-1.04</td>
</tr>
<tr>
<td>Use open-ended questions</td>
<td>484</td>
<td>1-5</td>
<td>4.47</td>
<td>.85</td>
<td>-1.74</td>
<td>2.79</td>
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<tr>
<td>Require students to supply evidence to support their claims</td>
<td>484</td>
<td>1-5</td>
<td>4.30</td>
<td>.92</td>
<td>-1.42</td>
<td>1.84</td>
</tr>
<tr>
<td>Encourage students to explain concepts to one another</td>
<td>484</td>
<td>1-5</td>
<td>4.26</td>
<td>.96</td>
<td>-1.42</td>
<td>1.83</td>
</tr>
<tr>
<td>Encourage students to consider alternative explanations</td>
<td>485</td>
<td>1-5</td>
<td>4.11</td>
<td>1.01</td>
<td>-1.02</td>
<td>.43</td>
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<tr>
<td>Have students participate in discussion with the students to further science understanding</td>
<td>486</td>
<td>1-5</td>
<td>4.26</td>
<td>.89</td>
<td>-1.20</td>
<td>1.19</td>
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<tr>
<td>Have students work in cooperative learning groups</td>
<td>484</td>
<td>1-5</td>
<td>4.08</td>
<td>.94</td>
<td>-1.07</td>
<td>.98</td>
</tr>
<tr>
<td>Have students share ideas or solve problem with each other in small groups</td>
<td>486</td>
<td>1-5</td>
<td>4.06</td>
<td>.92</td>
<td>-1.00</td>
<td>1.05</td>
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Overall, this model looks similar to the model in Figure 11, the main differences being the inclusion of a direct effect between Naïve and Investigative Practices, and smaller path coefficients from the dummy coded profiles to self-efficacy and the two types of teaching practices. The small coefficients reflect the smaller differences in self-efficacy and teaching practices between Sophisticated and Naïve and between Flexible and Naïve, as reflected in the MANOVA. When comparing Naïve and Sophisticated as in the model in Figure 11, the difference is larger, therefore the path coefficient is larger. The direct paths from self-efficacy to investigative practice and investigative culture stayed relatively consistent. Again, using the stdy standardization, there were also significant indirect effects from Naïve to investigative practice and investigative culture.
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