Exploring Relations between Teachers' Beliefs, Instructional Practices, and Students' Beliefs in Statistics

Melissa C. Duffy
McGill University

Krista R. Muis
McGill University

Michael J. Foy
John Abbott College

Gregory Trevors
University of Minnesota

John Ranellucci
CUNY Hunter College

International Education Research
Volume 4, Issue 1 (2016), 37-66
ISSN 2291-5273 E-ISSN 2291-5281
Published by Science and Education Centre of North America

Exploring Relations between Teachers' Beliefs, Instructional Practices, and Students' Beliefs in Statistics

Melissa C. Duffy[1], Krista R. Muis[1], Michael J. Foy[2], Gregory Trevors[3], John Ranellucci[4]

[1] Department of Educational and Counselling Psychology, McGill University

[2] Department of Psychology, John Abbott College

[3] Department of Educational Psychology, University of Minnesota

[4] Department of Educational Psychology and Special Education, Michigan State University

* Correspondence concerning this article should be addressed to Krista R. Muis, McGill University, 3700 McTavish Street, Montreal, Quebec, H3A 1Y2, or via e-mail at krista.muis@mcgill.ca

Received: October 25, 2015 Accepted: January 15, 2016 Online Published: April 7, 2016

DOI: 10.12735/ier.v4i1p37 URL: http://dx.doi.org/10.12735/ier.v4i1p37

Abstract

We examined the epistemic climate of statistics classrooms across two different classrooms by measuring teachers' espoused beliefs about teaching statistics and observing their teaching practices. We then explored whether students' beliefs became more aligned with the epistemic climate of the classroom over time. Post-secondary students' beliefs were measured at the beginning and end of the semester. To measure the epistemic climate, teachers completed self-reports of their beliefs about teaching and learning, and participated in two semi-structured interviews at the beginning and end of the semester. Moreover, several classroom observations were conducted over the course of the semester. Analyses of the data revealed that for one group of students in one class, their beliefs were well aligned with the classroom climate and remained stable over time whereas for the other group of students, their beliefs shifted over time to align with the classroom climate.

Keywords: classroom epistemic climate, pedagogical approaches, statistics, students' beliefs, teachers' beliefs

1. Introduction

What is the relationship between students' beliefs about statistics and instructional practices within the classroom? What influence do classroom climates have on students' beliefs? Questions such as these

How to cite this paper: Duffy, M. C., Muis, K. R., Foy, M. J., Trevors, G., & Ranellucci, J. (2016). Exploring relations between teachers' beliefs, instructional practices, and students' beliefs in statistics. *International Education Research*, *4*(1), 37-66. http://dx.doi.org/10.12735/ier.v4i1p37

have become increasingly popular among educational researchers, particularly in the fields of mathematics and statistics (National Council of Teachers of Mathematics [NCTM], 2010). Importantly, since the late 1980s, the NCTM (1989) has made explicit calls to teachers and teacher-training programs to adopt constructivist approaches to teaching statistics. The shift toward constructivist approaches to teaching is founded on the belief that changes in instruction will result in shifts in students' beliefs about knowledge and learning in statistics towards more constructivist views (Muis, Trevors, & Chevrier, 2016). Not only have these requests targeted elementary and secondary educational levels, they have expressed a need for change at the college and university levels as well.

Why might there be a call for a shift in students' beliefs about statistics? As Muis (2004) noted in her review of students' beliefs about mathematics knowledge and learning, many students across all levels of education enter mathematics classrooms espousing beliefs about knowledge and learning that potentially limit their ability to understand the relevance and application of this domain. For instance, they may view mathematics knowledge as fixed, consider only one correct answer to each problem, and believe that memorization of formulas is the only way to learn. These types of mathematics-related beliefs, which include students' beliefs about the nature of knowledge, learning, and teaching (Schoenfeld, 1985; Thompson, 1992), play an important role in students' learning processes and achievement outcomes (Muis, 2004, 2008; Muis & Duffy, 2013; Schoenfeld, 1985).

Although there is substantial research that has explored what students' beliefs are about mathematics and how they relate to various learning outcomes (e.g., De Corte, Op't Eynde, & Verschaffel, 2002; Garofalo, 1989; Kloosterman & Cougan, 1994; McLeod, 1992; Muis, 2004; Schoenfeld, 1985, 1989), we focus specifically on students' beliefs about statistics knowledge and learning, which builds from related work on students' mathematics beliefs. We also focus on statistics given that the NCTM has stated that, "a knowledge of statistics is necessary if students are to become intelligent consumers who can make critical and informed decisions" (NCTM, 1989, p. 105). Statistics literacy is considered to play an important role in education and decision-making given the multitude of data available within today's information society (Higgins, 1999; Rolka & Bulmer, 2005). If students' beliefs about statistics limit them from fully understanding and applying statistics to their everyday lives, then a better understanding of how these beliefs arise and how they might change is imperative. In this study, we examine students' statistics-related beliefs. Broadly defined, these encompass beliefs about the nature of knowledge, learning, and teaching in statistics, as well as students' perceptions of value and self-efficacy beliefs for statistics. To examine the role of the instructional approach and classroom climate, we focus more specifically on the epistemic nature of the classroom. We focus our review on these constructs (for a more detailed discussion of *epistemic beliefs*, see Hofer & Pintrich, 1997).

According to Muis *et al*. (2016), one factor that is related to students' beliefs is the classroom epistemic climate. Unfortunately, little is known about the nature of the epistemic climate at the college and university levels within which these beliefs operate. In particular, there is a need to better understand how constructivist and traditional epistemic climates relate to students' beliefs (Muis & Duffy, 2013). In the current study, we address this gap by exploring the epistemic climate of statistics classrooms to examine whether students' beliefs about statistics aligned with the epistemic climate. In the following sections, we describe previous research that has examined constructivist and traditional instructional practices in relation to students' beliefs and learning outcomes. We discuss the relevance of this work for the field of statistics by drawing on the literature for mathematics-related beliefs and statistics. The introduction closes with a description of the purpose and research questions for the present study.

1.1. Epistemic Climate

Epistemic climate refers to facets of knowledge and knowing that are salient in a learning environment. These various epistemic factors—or components of education—may include teachers' beliefs, learner beliefs, knowledge representations (e.g., textbooks, assessments, curricula), and pedagogical practices (Feucht, 2010; Haerle & Bendixen, 2008; Muis *et al*., 2016). Such factors and processes form the epistemic climate and can influence an individual's beliefs within the learning environment (Feucht, 2010). Within the classroom, there are several features that can be explored in relation to students' beliefs; however, one method is to explore the role of the epistemic climate by assessing the degree to which the pedagogical approach (i.e., instructor practices and classroom processes) reflects a more constructivist versus more traditional approach to teaching and learning statistics (see Muis & Duffy, 2013). Traditional views of teaching regard learners as passive recipients of knowledge and consider knowledge to be transmitted from an expert. These more traditional modes of instruction represent a teacher-centered approach, which often involves lecture and allows little room for collaboration or application. In contrast, constructivist views of teaching—a more contemporary approach—perceive learners as actively creating their own understanding of knowledge. While there are many different forms of constructivism, such as social, radical, cognitive, and sociocultural constructivism (see Cobb, 1994; Cobb & Yackel, 1996; Marshall, 1996; Murphy, Alexander & Muis, 2012; Prawat, 1996), most constructivist theorists maintain that learning is largely a personal process of meaning making that involves construction of knowledge from individual or interpersonal experiences (Murphy *et al*., 2012; Windschitl & Andre, 1998).

Within mathematics classrooms, constructivist instruction can be designed to encourage students to explore multiple pathways to solving a problem (Lampert, 1990; Muis & Duffy, 2013), and can promote inquiry (e.g., Yackel & Cobb, 1996), group work (e.g., Higgins, 1997) or authentic problem solving (e.g., Verschaffel *et al*., 1999). These approaches often result in increases in self-efficacy, value for learning, and learning outcomes (see Muis, 2004 for a full review). In contrast, traditional mathematics instruction often values speed of problem solving, accuracy in answers, and memorization of formulas and concepts, which can have negative effects on self-efficacy, value for learning, and learning outcomes (Muis, 2004). What might not be apparent from the descriptions provided above is that embedded within each classroom are structures and resources that convey messages about knowledge and knowing—in other words, epistemic messages (Feucht, 2010). Epistemic messages refer to information in the classroom that is relayed to learners (either implicitly or explicitly) about the nature of knowledge and knowing. These messages may be embedded within knowledge representations (e.g., textbooks or curriculum) or instructional approaches present in the classroom (Feucht, 2010). For example, an instructor wearing a lab coat may serve as a reminder of the demarcation between experts and novices and convey a message about knowledge residing in authority figures. Collectively, these messages can shape the classroom climate by transmitting information about how knowledge is created and shared.

Classroom climates—and corresponding epistemic messages—can be influenced and shaped by many factors including teachers' beliefs (Pajares, 1992; Buehl & Fives, 2009; Fives & Buehl, 2008, 2012) or worldviews (Powell, 1996; Olafson & Schraw, 2006). According to Pajares (1992), teachers' beliefs can be implicitly or explicitly expressed in their classroom routines. Similarly, based on their review of the literature, Maggioni and Parkinson (2008) concluded that the teaching strategies teachers use in their classrooms are related to their epistemic beliefs; that is, their beliefs about knowledge and knowing (Hofer & Pintrich, 1997). For instance, classrooms with instructors who espouse less constructivist epistemic beliefs are typically characterized by teacher-centered classroom discourse, a focus on terminology, and an emphasis on the value of procedural problem-solving rather than the value of the knowledge itself (Johnston, Woodside-Jiron, & Day, 2001; Lidar, Lundqvist, & Ostman, 2006). In contrast, constructivist beliefs relate to a greater sensitivity to students' potential misconceptions, shared classroom authority, interactive activities, as well as greater emphasis on the value of inquiry and interpretation (Cheng, Chan, Tang, & Cheng, 2009; Kang & Wallace, 2005; Maggioni & Parkinson, 2008).

It is important to note, however, that research has also found that teachers may believe in a specific teaching perspective or practice (e.g., believe in a constructivist pedagogy), yet behave in ways that are not in line with their beliefs or ideals (e.g., use traditional instructional approaches) (Kane, Sandretto, & Heath, 2002; Kang & Wallace, 2005; Fang, 1996; Olafson & Schraw, 2006; Levitt, 2002; Schraw & Olafson, 2003; Thompson, 1992; White, 2000; Windschitl, 2002). For example, teachers may report that group work is important when learning mathematics, yet only occasionally allow students to work together to solve mathematics problems during lessons (Thompson, 1992). Moreover, in some cases, teachers espouse constructivist beliefs about teaching and learning, claim they use constructivist approaches, yet classroom observations reveal primarily traditional approaches to teaching (Olafson & Schraw, 2006). Due to these types of discrepancies between beliefs and practices, several researchers have called for observations of classroom practices to verify implementation of instructional approaches (Fang, 1996, Kang & Wallace, 2005). As Kane *et al*. (2002) conclude based on their review of teaching beliefs and practices: "…research that examines only what university teachers say about their practice and does not directly observe what they do is at risk of telling half the story." (p. 177). To understand the nature of the relationship between teachers' beliefs, their pedagogical approaches, and students' beliefs, research is needed wherein both teachers' and student' beliefs are measured *and* classroom processes are observed.

How might teachers' beliefs and practices relate to students' beliefs? Feucht (2010) postulates that these different worldviews and instructional approaches (e.g., traditional versus constructivist pedagogy) may relate to students' epistemic beliefs through the epistemic messages presented in the classroom. Supporting this view, previous research across various domains has revealed that constructivist instructional approaches are positively related to constructivist beliefs among students (e.g., that knowledge is complex, tentative, and personally constructed), whereas traditional instructional approaches are related to less constructivist beliefs among students (e.g., that knowledge is simple, certain, and handed down by an authority) (e.g., Boscolo & Mason, 2001; Johnston *et al.*, 2001; Louca, Elby, Hammer, & Kagey, 2004; Muis & Foy, 2010; Smith, Maclin, Houghton, & Hennessey, 2000).

For statistics in particular, there is also some evidence to suggest that students in more constructivist-oriented classrooms adopt more constructivist beliefs compared to students in more traditional climates (e.g., Muis & Duffy, 2013). Research has also demonstrated that constructivist instructional practices are linked to more adaptive strategy use and motivation, like self-efficacy, among students compared to more traditional instructional environments (e.g., Hofer, 1999; Muis & Duffy, 2013; Muis & Foy, 2010). Less constructivist beliefs, on the other hand, have been linked to lower grades, less time spent on learning and problem solving, and negative attitudes towards mathematics in general (Muis, 2004, 2008; Schoenfeld, 1985). In response to this growing body of literature, over the past two decades there have been several calls for shifts in classroom instruction toward more constructivist methods (e.g., National Research Council, 1989; NCTM, 2010). Despite these findings and calls for constructivist pedagogy, traditional modes of instruction continue to persist, particularly within mathematics- and statistics-related domains.

Taken together, the findings from previous research suggest that epistemic climate (e.g., teacher beliefs and pedagogical practices), and student beliefs can intersect in meaningful ways. However, further work is needed to examine the nature of these relations. The research to date has largely employed one-point-in-time measures, rather than assessing whether students' beliefs align over time with the epistemic climate (Muis & Duffy; 2013; Pintrich, 2002). Moreover, to our knowledge, few studies have combined quantitative data with more qualitative approaches, such as in-depth interviews and observations of classroom practice, particularly at higher levels of education. Furthermore, the nature and role of the epistemic climate is not well understood. Thus, there is a need to more closely examine the epistemic climate and how it may relate to students' beliefs, particularly within math-related domains such as statistics. Although previous research has explored relations between the instructional approach or teachers' beliefs and students' epistemic beliefs (e.g., Hofer, 2000; Muis & Duffy, 2013; Muis & Foy, 2010), the present study expands on this work by examining whether the epistemic climate extends to students' domain beliefs about statistics more broadly, rather than beliefs that are solely epistemic in nature.

1.2. Integrating Beliefs and Contexts

To tie these lines of inquiry together in the present study, we draw on De Corte *et al*. (2002) framework, which serves as the foundation from which to explore multiple types of mathematics-related beliefs. De Corte *et al*. (2002) proposed a theoretical framework that focuses specifically on mathematics-related beliefs. In their framework, they suggest that the sociocultural environment within which students learn determines students' beliefs. Moreover, the ways in which individuals view the world and interact within that world reflect their understanding of the basic beliefs and fundamental knowledge shared with members of their group, including family, friends, and individuals working within that domain (Alexander, Shallert, & Hare, 1991). As such, learning is manifest in the interaction with the social and cultural contexts, as are students' beliefs.

In addition, De Corte *et al*. (2002) describe several types of mathematics-related beliefs, which they assume influence students' learning and problem-solving behavior through cognitive and motivational processes (Kloosterman, 1996; Schoenfeld, 1985). Broadly speaking, they delineate three types of general mathematics-related beliefs. These include: (1) beliefs about mathematics education, (2) beliefs about the self in relation to mathematics, and (3) beliefs about the social context, i.e., the context of mathematical learning and problem solving. Beliefs about mathematics education include beliefs about mathematics knowledge per se (e.g., mathematics problems have only one correct answer – a less constructivist view), beliefs about learning and problem solving (e.g., mathematics is mainly rote memorization – a less constructivist view), and beliefs about teaching (e.g., beliefs about what makes a good teacher, such as showing step-by-step procedures to solve problems – a less constructivist view).

The second category of beliefs, beliefs about the self, include more motivational beliefs, like achievement goals (e.g., a performance-approach goal wherein an individual strives to outperform others), task value beliefs (e.g., it is important to learn mathematics), control beliefs (e.g., studying will lead to good outcomes), and self-efficacy beliefs (e.g., confidence in being able to understand the most difficult material). Finally, the third category, beliefs about the social context, reflects beliefs about the classroom context. Importantly, mathematics educators have proposed that the formal mathematics education students receive has a major influence on the development of their beliefs about mathematics. Without excluding the importance of the general cultural environment and home environment, researchers have concentrated on sociomathematical norms (Yackel & Cobb, 1996) to account for how students develop specific beliefs about mathematics. This interactionist view assumes that cultural and social processes are integral to mathematical activity (Voigt, 1995). Taken from this view, the development of individuals' analytic and logical processes cannot be separated from their participation in the interactive constitution of taken-as-shared mathematics meanings. Thus, individuals are believed to develop their personal understandings and beliefs about mathematics as they participate in negotiating classroom norms specific to mathematics (Yackel & Cobb, 1996).

1.3. The Current Study

As Muis and Foy (2010) noted, to fully explore relations between teachers' and students' beliefs, a mixed methodology needs to be employed that includes quantitative data coupled with classroom observations and interviews. To respond to this call, we examined two classroom contexts in this mixed-methods study. Specifically, we measured students' beliefs about statistics at the beginning and end of a course in two different educational contexts; namely, at the college and university graduate levels. We observed instructor practices and measured their beliefs about statistics knowledge through self-reports, interviews and observations to provide in-depth analyses of the classroom climates. In particular, the purpose of this study was to examine instructor practices and beliefs—the epistemic climate—in relation to students' beliefs about statistics. Thus, our research questions are as follows: (1) What is the nature of the epistemic climate across two classroom contexts? (2) Do students' beliefs about statistics become more aligned with the epistemic climate over time?

Given the mixed-methods approach that we adopt here, we present only some hypotheses. Specifically, we predict that students' beliefs will become more aligned with the epistemic climate of their classroom over time. In other words, if students espouse more constructivist beliefs within a more traditional environment, we expect their beliefs to shift toward a more traditional approach. On the other hand, if students endorse more traditional beliefs about statistics and enter a more constructivist classroom, we expect their beliefs will become more constructivist over time. If students' beliefs match the epistemic climate of the classroom, then we expect students' beliefs to remain stable over time. In the following sections we describe the methodologies used in the present study.

2. Methodology

2.1. Participants

2.1.1. Participant Instructors

Sophia and Gilbert[1], instructors from two different schools, volunteered to participate in this study. As a college instructor, Sophia taught students for a total of two years. She was 30 years old. Gilbert taught graduate students at a major university for a total of 7 years. He was 32 years old. Both instructors taught an introductory social science statistics class as part of this study. Both classes covered the same topics, including concepts related to descriptive statistics (e.g., measures of central tendency and variability) and inferential statistics (e.g., hypothesis testing, correlation, regression, t-test, and ANOVA). Both courses were also comparable in terms of the types of assessments (primarily short-answer and problem-based exams and assignments) and level of difficulty of course material (introductory course with no prior course requirements in statistics).

2.1.2. Participant Students

Fifty-nine students ($N = 43$ from college, and $N = 16$ from graduate-level university) volunteered to participate. All students were enrolled in a required introductory social science statistics course. Of the 43 college students, 11 were enrolled in social sciences with commerce, whereas the other 32 were enrolled in the social sciences. Both groups of students were taking introductory courses in several fields of study (e.g., psychology, sociology, and anthropology) but the commerce students took additional math and business courses. The mean age of the college students was 18.05 (*SD*=1.45). All of the graduate students were pursuing Masters Degrees in education (i.e., Masters of Arts or Masters of Education). The mean age of the graduate-level students was 29.94 (*SD*=6.07). The college-level students were enrolled in a small public institution in Canada with a highly competitive entrance requirement. The graduate-level students were enrolled in a large public institution in Canada, also with a highly competitive entrance requirement. Both classes were considered to be comparable introductory-level statistics courses.

[1] Pseudonyms are being used to protect anonymity.

2.2. Materials: Students

2.2.1. Prior Knowledge

In consultation with Sophia and Gilbert, a 10-item multiple-choice test with five response options for each question was created to assess students' prior knowledge in statistics. The test assessed prior knowledge relating to five statistical concepts commonly included in introductory statistics courses, namely central tendency, frequency distributions and graphs, statistics notation, variance, and measures of central tendency. A sample item is: "For the data set (100, 100, 100, 20, 120, 90) find the mode of the data set, identify the outlier, and then find the mode excluding outliers: (A) 110, 120, 100; (B) 100, 100, 100; (C) 20, 100, 20; (D) 100, 20, 100; (E) 71.7, 20, 84." To score the prior knowledge test, correct responses were given one point, and incorrect responses were given a zero, with the highest possible score of 10 points. The mean score was 5.12 (*SD* = 1.94).

2.2.2. Mathematics-Related Beliefs

The Mathematics-Related Beliefs Questionnaire [MRBQ] (Op't Eynde & De Corte, 2003) is a 44-item questionnaire designed to measure students' mathematics-related beliefs across four subscales. For this study, the questionnaire was adapted to refer to statistics. Specifically, the word 'statistics' was used in the questionnaire items to replace 'mathematics' when referring to the domain. Moreover, students were instructed before completing the questionnaire to respond to questions based on their experience in the statistics course in which they were currently enrolled. The first subscale consists of 16 items that assess students' beliefs about the role and the functioning of their instructor (higher scores indicate beliefs of the teacher as more supportive; lower scores indicate beliefs of the teacher as less supportive). A sample item is, "Our teacher listens carefully when we ask or say something." The second subscale consists of 13 items that measure students' beliefs about the significance of and competence in statistics (higher scores indicate more constructivist beliefs, higher self-efficacy, and beliefs about statistics as highly valued, whereas lower scores indicate less constructivist beliefs, lower self-efficacy, and beliefs about statistics as less valued). A sample item is, "I can understand even the most difficult material presented in a statistics course". The third subscale consists of 9 items that assess students' beliefs about statistics as a social activity in terms of its accessibility and relevance to everyday life (higher scores indicate beliefs about statistics as more accessible and relevant; lower scores indicate beliefs about statistics as less accessible and relevant). A sample is, "Statistics is used by a lot of people in their everyday life." The final subscale consists of 6 items that measure students' beliefs about statistics as a domain of excellence, in terms of providing an opportunity to perform and excel (higher scores indicate more performance-approach goals; lower scores indicate less performance-approach goals). A sample items is, "By doing the best I can in statistics I want to show the teacher that I'm better than most of the other students". Participants respond on a 6-point Likert scale ranging from "completely disagree" to "completely agree." Raw scores were summed and averaged for each subscale.

2.3. Materials: Instructors

2.3.1. Beliefs about Learning and Teaching Mathematics

The Survey Belief Statements questionnaire [SBS] (Perry, Tracey, & Howard, 1999) was used to measure instructors' beliefs about mathematics. The instructors were told to respond to the questionnaire with a focus on the statistics course that they were teaching. The SBS is a 20-item questionnaire that measures instructors' mathematics beliefs relating to three subscales: (1) the domain of mathematics, (2) learning mathematics, and (3) teaching mathematics. These subscales are further divided into student-centered versus transmission-centered beliefs. The domain of mathematics subscale consists of three transmission-centered items such as, "Mathematics problems given to students should be quickly solvable in a few steps" and three student-centered items, including "Mathematics is the dynamic searching for order and pattern in the learner's environment."

The mathematics learning subscale consists of two transmission-centered items, such as "Mathematics learning is being able to get the right answers quickly," and six student-centered items, including "Mathematics learning is enhanced by activities which build upon and respect students' experiences." Finally, the mathematics teaching subscale consists of two transmission-centered items, such as "Teachers or the textbook -not the student- are the authorities for what is right or wrong," and four student-centered items, including "Teachers should provide instructional activities which result in problematic situations for learners." Participants respond on a 5-point Likert scale ranging from "completely disagree" to "completely agree." The three sub-scales were collapsed and raw scores were summed and averaged for transmission-centered (traditional) versus student-centered (constructivist) items.

2.3.2. Views of Teaching

The Teacher Belief Vignettes were used to measure instructors' worldviews of teaching (Schraw & Olafson, 2003; Olafson, Schraw, & Veldt, 2010). This measure consists of participants rating their degree of agreement with three short vignettes which each represent a different worldview and correspond to sets of beliefs about the nature of knowledge and knowing. The realist vignette assumes that there is an objective body of knowledge that is acquired via experts through transmission and reconstruction. The contextual vignette assumes that learners construct shared understanding in collaborative contexts in which instructors serve as facilitators. Finally, the relativist vignette assumes that each learner constructs a unique knowledge base that is different but equal to that of other learners (Olafson *et al*., 2010). Both relativist and contextualists can be considered to be similar to a constructivist approach, whereas realist views represent a more traditional perspective. Participants respond on a 5-point Likert scale ranging from "completely disagree" to "completely agree." Dominant worldviews were determined for each instructor based on the vignette that he/she agreed with the most. The vignettes were not domain specific, although both teachers were statistics instructors, so it is likely they reflected on this domain when reading vignettes. Since domain-specific observations and interviews were conducted with instructors we felt it would be useful to triangulate this data by also measuring instructors' broader epistemic worldviews.

2.3.3. Interviews

Two semi-structured interviews were used to gain deeper insight into Sophia's and Gilbert's perspectives, with a focus on their epistemic, teaching, and learning beliefs about statistics. The first interview was conducted at the beginning of the semester and consisted of open-ended questions that focused on their personal experiences about learning statistics, their attitudes toward the subject matter that they are teaching, and their general teaching style. Sample questions include: "Tell me about your experiences as a statistics student," "Tell me about some of the teaching strategies that you use in class," and "What do you hope your students will come away with from your class?"

The second interview was conducted at the end of the semester and consisted of open-ended questions that focused on what they felt worked well, whether they encountered any challenges or difficulties, and what they would change in their future classes. Sample questions include: "When you look back on this semester, tell me what comes to mind. Is there anything that stands out to you?" "Tell me about your students. Did they meet your expectations?" "Tell me about some of the challenges that you faced this semester. What would make your job easier?" Furthermore, the second interview acted as a follow-up to the previous interview and classroom observations. For example, Gilbert had the tendency of saying "this is very, very important…" or "always, always do…" in class, and consequently the interviewer asked the purpose of these statements. If Sophia or Gilbert did not offer much information, then specific pre-planned probes were used (e.g., "Would you elaborate on that?" "Could you say more about that?" "That's helpful. I would appreciate a bit more detail." "I am beginning to get the picture; tell me more"). All the interviews were audio recorded, transcribed and coded. Each interview lasted approximately 1 hour.

2.3.4. Classroom Observations

These observations were conducted to provide further insight into how Sophia's and Gilbert's beliefs about teaching and learning affected what they did in their classrooms. More specifically, observations were conducted to assess the epistemic climates of the classrooms and focused on their instructional approaches, student interactions, and the nature and content of classroom discourse. In particular, notes were made with regard to who asked questions, question topics, answer types, and whether any follow-up questions or probes were used. This observational data enabled triangulation with self-report and interview data to provide a means for close examination of the relationship between Sophia's and Gilbert's expressed beliefs and practices. As well, multiple sources of data allowed the researchers to corroborate instructors' beliefs by comparing the various sources of information to check for consistencies and similarities.

Researchers conducted six classroom observations with Gilbert and eight observations with Sophia. The observations ranged in length from one to two hours, included lecture and labs, and took place near the start, middle and end of the semester. For each observation, researchers arrived a few minutes before the start of class and found a place close enough to the instructor to document what transpired during the class. Researchers recorded observation field notes on their laptops and were careful to capture as many details as possible. This included documenting the time of day, dialogue, and other significant events, such as classroom activities, homework assignments, presentation slides, and chalkboard or white board notes. Observation record files were created for each of the instructors.

2.4. Procedure

Within the first two weeks of the course, students completed a general demographics questionnaire, the prior knowledge test, and the MRBQ. The MRBQ was completed again during the last two weeks of the course as the post-test. All questionnaires were completed online using a secure web-based survey tool that encrypts data to ensure privacy. Participants completed questionnaires online by following a link to the consent form and questionnaires. Sophia and Gilbert also completed their demographics questionnaire, the SBS, and the vignettes online during the first two weeks of the course.

2.5. Coding

Observation notes and instructor interview transcripts were analyzed by a group of five researchers. To analyze observations, coders identified segments from the notes that were determined to be relevant to the epistemic climate of the classroom. Specifically, coders reviewed observation notes for examples of events and discourse patterns (e.g., words, phrases, patterns of behaviors and communication) that represented either more traditional or more student-centered (i.e., constructivist) approaches to instruction across the following epistemic dimensions: simplicity of knowledge (simple versus complex), certainty of knowledge (certain versus tentative), and source of knowledge (external versus internal). These epistemic dimensions were selected for coding purposes, as they appeared to play a salient role in the classroom.[2]

We categorized codes as constructivist if the events presented knowledge as tentative and complex and suggested that knowledge originated within the student (internal). In contrast, we categorized codes as traditional if the events suggested that knowledge was fixed and simple and suggested that the knowledge originated with the instructor (external). Coders engaged in a similar process for interviews, although codes included both instructors' self-reported expressed and

[2] For the purpose of this study, we focused on comparing the traditional and constructivist codes; however, we draw on examples from the sub-categories (i.e., specific epistemic dimensions) to illustrate nuances when appropriate.

enacted beliefs about statistics. Specifically, responses to interview questions were coded using the following categories: instructional practices or approaches to teaching statistics, beliefs about statistics knowledge and learning, and constraints or challenges to teaching. Within these categories, we coded responses as traditional or constructivist using the same criteria as previously described for the observation notes. Segments were created using individual idea units (Chi, 1997). Team members coded observation notes and interview transcripts independently and then met to discuss codes and corresponding examples/quotations, as well as key patterns and thematic analyses of these data; discrepancies were resolved through discussion. There was 100% agreement with the categorization of each teacher's instructional approach, which we consider to represent a global indicator of inter-rater reliability. Despite the use of predominantly theory-driven categories, we also heeded Creswell's (2007) recommendation to allow additional codes to emerge from the data during analyses. For instance, the inclusion of the *constraints* category for instructor interviews was a response to team discussions, instructor comments, and discrepancies between instructor practices and their self-reported beliefs.

2.6. Validity

Consistent with a qualitative approach, several methods were used to establish credibility and dependability of the qualitative data and analyses (see Creswell, 2007). First, interviewers conducted observations of the classrooms and met with the instructors several times throughout the semester in an effort to establish rapport. During the interview, efforts were made to clarify points and check understanding by paraphrasing the instructors' statements and using follow-up probes to improve accuracy (e.g., "If I understand correctly…" "Is there anything I am missing?" "Is there anything you would like to add?" "Can you tell me what you mean by that?"). We also explained to instructors that there were no right or wrong answers and that we were interested in understanding their perspective and experiences. In addition to holding team meetings to discuss and verify emerging themes and patterns from observational and interview data, we also collected multiple measures as a method of assessing the validity of our interpretations. For example, instructors' ratings for the Teacher Belief Vignettes (Schraw & Olafson, 2003; Olafson *et al.*, 2010) and Survey Belief Statements (Perry *et al.*, 1999) were reviewed after analyses of the interviews to compare results with questionnaire responses as a method of establishing credibility through triangulation of data. Results demonstrated consistency between qualitative and quantitative findings with respect to instructor's self-reported beliefs as described in the following sections.

3. Results

3.1. Preliminary Analysis

3.1.1. Instructor Data

We first examined the nature of Sophia's and Gilbert's espoused beliefs about teaching and learning in statistics. Based on their scores on the epistemic worldview vignettes (which measure broader epistemic stance), Sophia can be described as more contextualist (i.e, constructivist), as she scored 5 on the contextualist scale compared to a 2 on the realist (traditional) scale and a 3 on the relativist scale. Consistent with this characterization, Sophia also scored highest on the student-centered, constructivist approach to teaching scale on the SBS, with a score of 4.23 compared to a score of 1.71 on the traditional, teacher-centered scale. In contrast, Gilbert scored 4 on both the realist and contextualist scales, compared to a 3 on the relativist scale, but scored 3.92 on the student-centered constructivist scale on the vignettes compared to a 1.86 on the teacher-centered, traditional approach to teaching. As such, based on self-reported beliefs, we would characterize Sophia as more contextualist and student-centered in her approach to teaching (i.e., constructivist) compared to Gilbert, who was more mixed and perhaps, compared to Sophia, more realist or (i.e., traditional) in his views of teaching and learning[3].

3.1.2. Student Data

Prior to examining potential shifts in students' espoused beliefs, we first examined subscale scores for normality. Kline (1998) suggested using absolute cut-off values of 3.0 for skewness and 8.0 for kurtosis. All subscales on the MRBQ were well within these ranges (ranging from -1.84 to .48 for skewness and from -1.03 to 1.27 for kurtosis). We then examined whether there were any differences between the two groups on prior knowledge. Results from an independent samples t-test revealed significant differences between the two groups, $t(57) = 2.51$, $p = .01$, wherein students enrolled in Sophia's course performed better on the prior knowledge test ($M = 5.49$, $SD = 1.93$) compared to the students enrolled in Gilbert's course ($M = 4.13$, SD = 1.63). Given these differences, prior knowledge was used as a covariate in subsequent analyses[4]. Table 1 presents descriptive statistics for each subscale of the MRBQ at pretest and posttest along with Cronbach's alpha for reliability for both pretest and posttest.

Table 1. Means and Standard Deviations for Each Subscale on the MRBQ as a Function of Educational Level over Time

	College Level				Graduate Level	
	Pretest Mean (*SD*)	Posttest Mean (*SD*)	α(pre)	α(post)	Pretest Mean (*SD*)	Posttest Mean (*SD*)
Dimension						
Teacher	4.60 (.45)	4.51 (.44)	.53	.65	4.61 (.39)	4.61 (.35)
Competence	4.27 (.61)	4.24 (.67)	.74	.71	4.36 (.75)	3.89 (.69) *
Social	4.54 (.64)	4.41 (.77)	.75	.72	4.47 (.69)	4.41 (.69)
Excellence	3.79 (.82)	3.82 (.99)	.57	.71	3.48 (.80)	3.55 (.92)

Note: *SD* = standard deviation. * denotes statistically significant difference at p < .05.

3.2. Relations between the Epistemic Climate and Students' Espoused Beliefs

To examine whether students' beliefs shifted over time, we conducted a repeated measures ANCOVA with time and each of the four belief dimensions as the within subjects variables, classroom as the between subjects variable, and prior knowledge as the covariate, for a 2 (time) by 4 (dimension) by 2 (group) design. Results revealed no differences between groups collapsed over time (no main effect of group), but a significant main effect for time, Pillais Trace = .13, $F(1, 56) = 8.40$, $p < .005$, $\eta^2 = .13$, and a significant main effect for dimension, Pillais Trace = .61, $F(3, 54) = 29.05$, $p < .001$, $\eta^2 = .40$, was found. Follow-up post hoc analyses revealed that students' beliefs generally decreased from pre-test to posttest. Simple effect analyses revealed that the source of change from pretest to posttest was a change in Gilbert's students' beliefs about the significance of and competence in statistics, wherein their beliefs significantly decreased over time; in other words,

[3] Realist is considered to reflect a more traditional stance, whereas contextualist and relativist are considered to represent a more constructivist approach.

[4] Given the age differences between the two groups, we also assessed whether age was a significant covariate. Age did not play a role in the analyses, and thus was not included in those reported here.

this indicates that these students espoused less constructivist beliefs, lower self-efficacy, and less value towards statistics at the end of the semester compared to the beginning (see Table 1).

For differences across the subscales, post hoc analyses revealed that their beliefs about the instructor (M = 4.59, SD = .43) and beliefs about statistics as social (M = 4.47, SD = .70) did not differ (p > .05), but that these two belief scales significantly differed from students' beliefs about the significance of and competence in statistics (p < .01, M = 4.20, SD = .68) and their beliefs about statistics as a domain of excellence (p < .01, M = 3.65, SD = .89), wherein their beliefs about the significance of and competence in statistics (self-efficacy, value, and constructivism) were lower and students were less likely to report wanting to outperform other students. In the next section, we describe the nature of the epistemic climate in each classroom to help interpret why Sophia's students' beliefs remained stable over time, whereas Gilbert's students' beliefs shifted over the course of the semester.

3.3. Classroom Observations and Instructor Interviews

Qualitative analyses were conducted to explore the nature of the classroom epistemic climate based on instructors' practices and beliefs. Specifically, we examined Sophia's and Gilbert's beliefs about teaching and learning in statistics and how these beliefs related to their instructional practice. Although their self-reported beliefs about statistics were more constructivist in nature, qualitative analyses revealed that Sophia was more mixed in her approach to teaching, whereas Gilbert typically engaged in a more traditional instructional approach. In the following sections, we elaborate these findings by describing results from observational data (discourse, activities, and interactions), as well as key themes from the instructor interviews[5].

3.3.1. Gilbert's Class

*Classroom Observations***.** Overall, analyses of the observation data revealed that Gilbert demonstrated a more traditional approach toward teaching statistics (examples of instructor discourse and practices are illustrated in Table 2) compared to Sophia (discussed below), and often made statements or engaged students in activities that might foster less constructivist beliefs about knowledge and knowing (e.g., that knowledge is certain, simple, and handed down by authority). For example, analyses of field notes revealed that Gilbert appeared to serve as the primary source of knowledge, as he expressed definitive answers to students' questions and frequently told students whether their answers to his questions were right or wrong. In many cases, students were prompted to respond to questions that Gilbert posed, who would then indicate whether or not the answer was correct with responses such as: "Yes, you are right" and "No, you cannot say that." Even without these prompts, students frequently verified with Gilbert whether their understanding of a concept was correct.

Furthermore, Gilbert often reinforced a point by emphasizing the unchanging or fixed nature of knowledge in the field, as the following quotation from Gilbert illustrates: "…always, always, always the df [degrees of freedom] of a numerator is smaller than the df of the denominator." In another instance, Gilbert stated: "always the fail to rejection area is related to the null" and repeated this statement several times while adding, "remember." In another instance, when a student asked Gilbert to clarify a point, Gilbert instead invited another student to respond, but then followed this by confirming whether the explanation was correct. In these examples, the authority for knowledge verification rested with Gilbert. Similar to these traditional instructional practices, the answers in slides were often written in bold, which conveyed that there was only one correct answer. Overall, these practices demonstrated a more traditional rather than constructivist approach to teaching and learning statistics.

[5] Analyses of interviews and observations indicated that beliefs and pedagogical approaches were generally stable over time, although we note exceptions when applicable (e.g., change in response to student reactions or plans to change practices in the future).

Despite the predominant tendency to adopt a traditional approach to teaching, there were notable instances where Gilbert employed more constructivist practices. For instance, to start one class Gilbert used a concept map, which represented a more constructivist approach as it prompted students to draw on topics previously covered in the course and allowed them to explore the integration of concepts based on their own knowledge and experience. Links to prior knowledge were also made throughout the lecture, as the following quotation from Gilbert demonstrates: "it [t-test] is very similar to z-test. Do you remember z-test?" These types of practices suggest that knowledge is complex and consists of integrated ideas rather than isolated facts. Although the question-response discourse between Gilbert and his students typically represented a traditional exchange between expert and pupil, there were some instances in which Gilbert acknowledged that the most appropriate course of action or interpretation could change "…depending what your research question is." In this way, Gilbert acknowledged that the best decision is tentative and depends on the context. Finally, at one point during the course, Gilbert asked his students to exchange explanations with one another instead of with him. This method of co-creating knowledge among students suggests the source of knowledge did not rest exclusively with Gilbert. Yet, these types of activities were noted far less frequently in classroom observations compared to more traditional lecture approaches.

Table 2. Graduate Instructor Observation Codes and Classroom Practices

Traditional		Constructivist	
Code	Example	Code	Example
Simple	Instructor: "Step one… step two…" Instructor: "remember"	Complex	Instructor begins by showing a concept map. Connects concepts with concept map. Instructor refers back to the topics previously covered.
Certain	Answer to the example shown in bold on the presentation slide Instructor provides answers and confirms those answers throughout. Instructor demonstrates distributions on the board Instructor: "always, always, always the df of a nominator is smaller than the df of the denominator." Instructor: "always the fail to rejection area is related to the null"	Tentative	Student comments: "otherwise, it is meaningless." Instructor responds: "No [no, you can't say that], depending what your research question is". Instructor: "stats is very creative."
External Source	Instructor demonstrates on the board. Students ask questions and instructor provides answers. Instructor affirms students' answers Instructor: "Yes, you are right." Instructor: "No, no you cannot say that." Instructor: "Important, very, very important, take a note"	Internal Source	Instructor invites answers from students. Students check answers with each other. A student asks: "do you mean the smallest value of F is one… why the sampling distribution starts from zero?" Instructor (to student): "that's a good question". A student offers an example to explain what the instructor said. Instructor responds: "that's a good example"

Table 3. Graduate Instructor Interview Responses and Codes

Traditional		Constructivist	
Code	Example	Code	Example
Teaching Approach and Practices	… For that reason I prefer more to not work on that kind of, how can I say that, like social oriented activities. Basically I think that in this semester they prefer more interaction between the teacher and the student than between students.	Teaching Approach and Practices	To be sensitive to their concerns, expectations, and the way in which you align your expectations with their expectations so it's going to be a success for everybody. Well I think that the more interactive the class the better. And I have found that when they have the chance of working together, that's very important. So these kinds of simulators are really interesting for them.
Beliefs about Statistics Knowledge and Learning		Beliefs about Statistics Knowledge and Learning	The content of their questions made me think that they were really understanding the concepts. I think stats, it's something, it's more something you need to integrate into your world […] into your daily life. …way of thinking it's more important to apply the concepts [thinking about changes to make in the future]. That stats, it's something you can use, it's a tool that researchers usually use in order to support their assumptions. That stats, for me, that's my personal opinion, it's kind of like a language. A logic to understand the reality.
Barriers and Constraints	Because they felt that, okay, it's kind of mathematics, it's memory, it kind of boring, I'm not good at math, so it's going to be a long term [students' negative attitudes and preconceptions about math]. People think that they need to be super mathematicians in order to succeed in the class. Sometimes they think that because they are, because they didn't do well in math, so they aren't going to do well in this statistics. The other thing that I think, that I consider was challenging, was how to cover all the topics. You know? Sometimes I felt that, hmm, we ran out of time, when teaching some techniques. Sometimes you need to go faster People think that stats is a course, or it's something that happens in your schedule and it's like a compartment you know… Well I think that something that I have to re-evaluate is the evaluation system. The majority of them were concerned all the time about exams, you know? That's all the reason why exams should be, not removed, but given a different priority within the evaluation scheme. Because they were all the time taking notes and saying 'well I don't understand that, could you rephrase that?' 'Is this important is this going to be in the exam?' And I'd have to say, that sometimes I have to struggle with some beliefs, preconceptions of the students and my own preconceptions and my own beliefs on stats.		

Instructor Interviews. Analyses of the initial interview revealed that Gilbert adopted a more constructivist view towards statistics knowledge (excerpts of Gilbert's interview responses are illustrated in Table 3). He considered statistics to be "a language", "a way of thinking", and a "logic to understand reality" rather than a "fixed, simple calculation." Based on his experiences as a student and instructor, he expressed the importance of delivering a higher-order message about statistics to the students. Specifically, he felt that a good statistics instructor should be passionate about statistics and provide opportunities for "hands-on way[s] of learning stats." Following this line of thinking, Gilbert also emphasized the importance of interpretation and application in learning statistics knowledge.

In the second interview, conducted at the end of the semester, Gilbert described the major challenges he faced during the semester; namely, the negative attitudes and perceptions that students held about statistics upon entering the class. As Gilbert described: "because they felt that, okay it's memory, it's kind of boring, I'm not good at math, so it's going to be a long term." He noted that students believed that success in statistics was linked to ability in mathematics: "people think they need to be super mathematicians in order to succeed in the class."

Gilbert also reflected on his experience with the course and expressed satisfaction in students' conceptual change. When discussing this, Gilbert conveyed a constructivist message about the purpose of the class: "I think in the end they [the students] understand that the class was not about memory or it was not about calculation but it was more about concepts and how to apply these concepts in their real lives…" Gilbert noted, however, the challenge of time constraints when covering course material, as well as the challenge of selecting appropriate assessment methods. In this regard, he noted that in the future he would prefer to place more weight on assignments than tests and quizzes given that the assignments provided a better assessment of "real world application of stats." Another challenge was the pressure to teach to the test, as the students appeared concerned about what they needed to know for the exams. Interestingly, Gilbert noted that group interactions did not occur as frequently in the course because, according to students' mid-term feedback, they did not see the value. Gilbert speculated that this may be due to their concerns about assessment: "…the majority of them were concerned all the time about exams… 'is this important? Is this going to be in the exam?" As such, the students presented an obstacle in terms of their past experiences with mathematics instruction as did more traditional assessment methods. That is, they had come to expect a more traditional classroom and voiced concerns over any departures from the material that was going to be on the test. As well, Gilbert felt that students preferred student-teacher interaction (a more traditional approach) rather than student-student interaction, which is consistent with the discourse patterns observed in class.

3.3.2. Sophia's Class

Classroom Observations. Overall, analyses of the observation data revealed that Sophia demonstrated a mix between constructivist and traditional practices in the classroom (examples of instructor discourse and practices are illustrated in Table 4). Messages and classroom practices would indicate that she was the source of knowledge, yet at other times students were encouraged to construct their own knowledge of statistics. For example, when Sophia served as the source of knowledge, she would relay to students that she was responsible for verifying whether an answer or interpretation was correct. As Sophia walked around the class, she would state: "if you have the answer put your hand up" and would check whether students arrived at the correct solution. Afterward, Sophia would show the class the correct answer with a set of steps taken to solve the problem: "I put the answers here, you can just double check to see if you're off somewhere."

Table 4. College Instructor Observation Codes and Classroom Practices

Traditional		Constructivist	
Code	Example	Code	Example
Simple	Instructor: "interpretation is just a few words. For example: most people have high trust." [paraphrased] Instructor: "Always remember: high, high or low, low" (for positive correlation) Instructor: "Two really important things you need to know with the Pearson correlation coefficient, if you calculate it and it's larger than 1 you've down something wrong." Instructor walks through the "steps" to calculate correlation. Instructor comments that she would not get full value for the hypothesis on slide and asks the class why that is. Student answers: the variables. Instructor replies: "yes, because I didn't include the variables so I would lose a point." Instructor: "are you doing it step-by-step?" Instructor reminds the class about how to look for "hints or little tricks."	Complex	Instructor: "The last little bit we're going to learn is just an extension of what we've learned already." Instructor asks what it would look like presented another way, connects current topic to skewness—a concept presented previously. Instructor: "Ah: that's a very complex relationship. I'm not sure if it's perfect." Instructor reminds class they are revisiting concepts they've learned about before Instructor relates regression to correlation and describes how it is different. Student: "so we have 4 different hypotheses?" Instructor: "yes - pick 4 relationships [...] the relationship will determine the analysis."
Certain	Instructor says: "So you have all of the components that you can take to plug into the formula."	Tentative	Instructor provides an example of poverty and politicians, explaining what different interpretations there are when different types people present either the median, mean, and mode for the same data set. Instructor: "if you were this person, what would you present? If you were this other person, what would you present? What would you present, what's the best answer here? median distorts the truth. Each value/statistic brings something, not presented by itself." Instructor: It's a description of the human bias inherent in statistics; one statistic can show a decline in poverty, whereas the other one doesn't -- which to choose depends on the person's motives. It shows the subjective nature of statistics. Instructor: "this is important because I'm going to ask you when to use mean vs. median."
External Source	Instructor says: "I put the answers here; you can just double check to see if you're off somewhere." Instructor: "this is your problem; this is where you went wrong." Instructor: "No I'll just tell you guys."	Internal Source	Instructor: "don't copy in text, follow the logic." [paraphrased] Instructor: "There's no point copying, you need to know!" Instructor emphasizes interpretations (tells students that they will not get full value for just writing 'a relationship between x and y, they need to include the variable names, need to be able to interpret, to get full value.' Instructor: "Normally I tell students what to do, but this time you get to choose what to do, not follow the rigid 4 step model. So you're going to be like a researcher trying to figure out what to do. It's going to be more challenging." Instructor: "I'm not going to tell you what to do anymore, you're going to have some freedom." Instructor: "Again you shouldn't have to look at this interpretation [instructor's], you should be able to figure it out at this point."

When explaining how to solve the various types of problems, Sophia would present a procedural step-by-step method of how to arrive at the same solution, stating: "guys listen up, the way I like to organize it…" Sophia would refer to this procedure when circulating the room to assist students: "are you doing it step by step?" Even when emphasizing the importance of interpreting a statistical value, Sophia would often demonstrate how students should phrase a particular interpretation or otherwise present their calculations and answers on her presentation slide. Alternatively, if the students were invited to offer an interpretation (e.g., "see if you can try and interpret the slope"), Sophia would confirm whether or not it was acceptable (e.g., "perfect") and then repeat the phrasing of the interpretation to the class. These types of discourse patterns and procedural presentations of statistics communicate the message that there is one path to solving a problem and one acceptable answer, which is verified by the expert.

In contrast to these more traditional methods, Sophia also presented statistics knowledge by drawing on more constructivist practices. Sophia often emphasized the importance of interpretation and related concepts in the class to real world situations. In these instances, she would invite students to share ideas and consistently encouraged them to provide their own examples. For example, when describing the concept of correlation, Sophia first asked her students to think of examples of two variables that would relate to one another in everyday life. In some instances, Sophia also acknowledged the complex and tentative nature of knowledge in the field as the following quotations illustrate: "we'll just leave that open-ended for now" and later, "that's a complex relationship, I'm not sure if it's perfect." When asked by a student why they were expected to conduct calculations by hand rather than relying on the computer program, Sophia responded: "because if you just use that, you won't internalize it." This type of response suggests that Sophia felt there was something important to learn beyond a computer-automated process. Additionally, at several times during the class, Sophia made clear links between new topics to prior knowledge, "remember [it's] just like hypothesis testing." She also encouraged students to exchange questions and solutions with other students while working on class problem-solving activities.

Instructor Interviews. Analyses of the initial interview with Sophia revealed that she held both constructivist and traditional beliefs about statistics (excerpts of Sophia's interview responses are illustrated in Table 5). In terms of a constructive perspective, Sophia felt that statistics involved "application" and was used to "…understand something about the social world." As she explained: "statistics is not just a number but an interpretation of what this number means." Sophia explained that she applied this perspective in the classroom by assigning authentic activities to help students develop skills that would be valued in the real-world: "I make them do things like re-coding and a lot of interpretation because if you're going to work in the field, these are the things that you need to know." Following this approach, Sophia brought in "real data" to help students build connections with the world around them: "I try and make it exciting and interesting for them…" During this interview, she conveyed her enthusiasm toward statistics, which she developed from her personal educational and work experiences: "for me, you know I was really lucky because I actually wanted to teach stats." Sophia's responses suggested that she wanted students to learn the material on a deeper level: "I don't want them to just regurgitate the information." She also noted that she encouraged students to work together and take "onus" for their learning rather than relying exclusively on her: "I want them to think, 'well maybe someone apart from [the instructor] can help.'"

More traditional perspectives on teaching and learning statistics were also demonstrated in the interview. Specifically, although Sophia emphasized the importance of interpretation, when asked how students learned this, she responded "through me" and noted that when practicing interpretations, students would ask: "what exactly do you want us to write?" She continued to explain how interpretations were taught in class: "I repeat it over and over and plus whenever I have any [presentation slides], I always write the interpretation… and sometimes I'm like: 'write it down, write down word for word.'" Sophia also spoke about prompting students to use rehearsal strategies during problem-solving as the following quote illustrates: "try to work it out and if you don't get to the right answer, cross it out, do it again." Although Sophia continually emphasized the advantages of this procedural technique (e.g., "often times the best way to learn something is to write it over and over again or say it over and over again"), there is some indication that she believed that this process involved deeper learning when recalling her personal experience learning statistics: "I would do it until the formula was memorized and not just for the sake of memorizing it but just you've done so much that you understand it." However, it was not clear how these memorization strategies translated into deeper level understanding or whether this message was communicated to students.

Table 5. College Instructor Interview Responses and Codes

Traditional		Constructivist	
Code	Example	Code	Example
Teaching Approach and Practices	The correct answer is given at the back of the textbook so I told them 'try to work it out and if you don't get to the right answer, cross it out, do it again.' I made them write definitions for like 15 concepts; I made them do questions from every single chapter. … But again, is this just because I say it so often that it's kind of like ingrained? I repeat it over and over and plus whenever I have any Power Points[TM], I always write the interpretation. So they have it written. Plus I interpret it and plus we interpret it in class and sometimes I'm like: "write it down, write down word for word." And again, often times the best way to learn something is to write it over and over again or say it over and over again. So sometimes they're a little bit unsure and I think because I'm so picky about interpretation often times, they make me repeat myself, they're like: "well what exactly do you want us to write?" Because they know that I take points off for everything. Students copied notes from slideshow presentations word-for-word and didn't seem to know how to identify the most important points or when to elaborate on key concepts…they're re-writing the same thing over and over. They don't take a critical distance in terms of what's important information and what's not. You have to teach all the foundations, you don't have time to on top of that to spend weeks trying to give them complex problems and you figure it out. It should come later on.	Teaching Approach and Practices	I also make them do more stuff than the other teachers. I make them do things like re-coding and a lot of interpretation because if you're going to work in the field, these are the things that you know. The interpretation is always worth more and the reason is… when you're working for any agency, when you're working as a research assistant, you're not doing stuff by hand. So I go conceptual, then I try and explain the different statistics, then we go through the formulas together with the interpretation. I use real data… so that they see that, you know, this is data that researchers use, that politicians use, that organizations use, and that we use it to try to understand something, we use it to affect social change, to bring about policy, to bring on new programs, etc. We use it for something. I try and really make them understand that it's part of a much larger social science discipline, so I think they understand that.

(To be continued on the next page)

(To continue)			
Beliefs about Statistics Knowledge and Learning	But for me, statistics, you just do it. You do it and you do it and you do it. That's it. So the more time I make them do it, hopefully the easier for them it will be. You know? And then when I start the lecture the following [class], I revise what was done. So I'm like: "don't forget guys, we did this, we did this, and we did this, now that you know this, we're moving on here." It's just about repetition. Repetition, repetition, repetition. It's the only way that you learn this stuff. Do work. Over and over and over again	Beliefs about Statistics Knowledge and Learning	Well for me, social statistics is not just a number but an interpretation of what this number means. You can learn something about the social world with statistics. It's not the only truth right… but it's one way of getting at understanding… I'm trying to make them understand it that you can learn something about the social world with the use of statistics. I told them, you have to ask 2 other people first before you ask me. Because you know, there are people around that know. So figure it out together. Brain-storm… I want them to think; well maybe someone apart from me [the instructor] can help.
Barriers and Constraints	I think what took me back was the level of discipline and I think that's the most frustrating part of teaching. The fact that you have to discipline and teach people to learn. …We spend more time talking about discipline than we do about the subject matter. we all have to give 3 exams, we all have to give between 6 and 9 assignments, we all have to give 2 lab reports. So essentially, we all have to give the same assignments, same number of stuff but the content we put in it is ours and how we teach is ours and how we choose to present is ours. …I can't stand the textbook that we are using but I am forced to use it. … it's them compared to everyone else, so it kind of puts pressure as well on the teacher because you don't want to be too high above the average or too low above the average. You don't want your standard deviation to be too high because that means some students are doing incredible and some are doing horrible. Anyway I think about these things. In terms of: how am I comparing compared to the rest of the teachers. We don't go back. Cover something, move on, cover something move on. So there is a whole bunch of stuff here that I'm like yeah maybe they need clarification on something, but we've already covered two chapters since the exam was graded. This is the nature of the educational system. You clearly outline you want this, this, that. As long as they're able to follow instructions, they've met the criteria. There's not a lot of critical thinking. There's not a lot of: 'well I'm just an independent person and I'm going to go and do what I think is right and I'm going to negotiate the challenges.' So again, everything is very structured. And I think until they come to a point where they have to do independent research that allows them to use the things that they've learned in these different courses, we will not know how much of that material is internalized.		

During the follow-up interview, Sophia reflected on her experience with the course and commented on several challenges to teaching statistics. Most notably, the key themes that emerged from the responses included time constraints (e.g., insufficient time to delve deeper into concepts or revisit material); class management issues (e.g., disruptive talking or distracting behavior from students that directed attention away from course-relevant material); and administrative regulations (e.g., fixed assessment methods and course outlines). These types of challenges may have played a role in limiting constructivist practices within the classroom, which we discuss in more depth below. In the following section, we summarize our analysis of Gilbert's and Sophia's practices.

3.4. Summary of Instructional Practices

In both classes, Sophia and Gilbert encouraged students to share examples, answers, and questions. They also monitored students' understanding throughout the class, were attentive toward students' emotions (i.e., anxieties about learning statistics), misconceptions, and apprehensions, and made a concerted effort to link new concepts with prior knowledge. Importantly, Sophia and Gilbert also conveyed an enthusiasm toward the field of statistics and its application to real world problems. In these ways, Sophia and Gilbert encouraged students to become active participants in the learning process and to consider the relevance of statistics for understanding the world around them. However, the classroom practices fell short of fostering a predominantly constructivist environment given that more traditional practices were used for knowledge verification and problem solving. Specifically, the source of knowledge often appeared to reside within Sophia and Gilbert, who confirmed whether or not a response was correct.

In addition, both instructors often presented knowledge in an absolute manner through words such as: "remember," "never," and "always." Moreover, the problem-solving aspects of statistics were typically presented in a procedural manner and involved one correct solution, which they arrived at through a step-by-step procedure. Despite endorsing more constructivist beliefs about the field of statistics, such as the value of interpretation and real-world application, Sophia's and Gilbert's constructivist views did not translate into instructional practices across the spectrum of approaches within which they engaged. In the following discussion section, we discuss possible reasons for these discrepancies, as well as the relations between the epistemic climate and students' beliefs. We close with a discussion of theoretical considerations and recommendations for practice.

4. Discussion

The purpose of this study was to assess the epistemic climate of two classes, and examine whether students' beliefs about statistics shifted as a function of the epistemic climate. Consistent with previous research (e.g., Muis, 2004), results from quantitative analyses revealed that students in both classes reflected beliefs about statistics that were just slightly above the neutral position on the Likert scale (around a score of 3.5 to 4.5 out of 6 across subscales). Based on these scores, we infer that students espoused slightly constructivist beliefs about statistics, as well as a slightly positive valuing of statistics, moderate levels of self-efficacy, moderate performance-approach goals, and beliefs about teachers as having supportive roles for teaching statistics.

Interestingly, despite the similarity between groups with regard to their espoused beliefs, the epistemic climates differed somewhat. Specifically, despite his mixed espoused views about teaching and learning (being both traditional and constructivist), we interpreted Gilbert's pedagogical approach to be more traditional and teacher-centered compared to Sophia's, which was more of a mix between traditional (teacher-centered) and constructivist (student-centered). We further interpreted Sophia's mixed approach as being somewhat in contrast to her own espoused beliefs (primarily constructivist), but perhaps in line with her students' beliefs; wherein some messages and approaches were more constructivist, others were more traditional. It may be the case that students in Sophia's classroom did not shift their beliefs given the consistency between their beliefs and the epistemic climate. For example, if students initially espoused more constructivist beliefs and relatively high self-efficacy and were also able to adapt to the constructivist classroom practices as they occurred throughout the course, then we would not expect to see significant change in these beliefs about statistics.

In contrast to Sophia's approach to teaching statistics, Gilbert's approach was more traditional in certain respects. In particular, messages and instructional approaches in his classroom were reflective of beliefs that the teacher is the source of knowledge and that knowledge is certain and not likely to change over time. Although students in his classroom, like Sophia's class, espoused slightly constructivist beliefs, self-efficacy, and valuing of statistics at the beginning of the semester, unlike the students in Sophia's class, students' beliefs (in these aspects) in Gilbert's class significantly decreased by the end of the semester. It may be the case that this shift was related to the epistemic climate in Gilbert's classroom. These results are important to consider, particularly given that both Sophia and Gilbert espoused more constructivist beliefs about teaching and learning. It is likely that there were factors that impeded their attempts to employ more constructivist approaches, which they delineated in their interview. We describe these next.

4.1. Challenges in Engaging in Constructivist Approaches

From our analysis of the interviews with Gilbert and Sophia, the main challenge appeared to be employing constructivist practices for problem solving (e.g., calculating a t-test) and explanations. In light of the finding that students' beliefs did not shift from the beginning to the end of the semester in Sophia's class, it is possible that the more traditional aspects of her classroom practices may have limited the extent to which students' beliefs about statistics shifted. In other words, it may be the case that the environment itself did not provide a sufficient catalyst for change in students' beliefs about statistics. It may also be the case that beliefs are deeply rooted and difficult to change (Muis & Duffy, 2013).

Furthermore, students' beliefs did not significantly differ at different levels of education. This is interesting given that Sophia felt that higher-level conceptual understanding and application would occur later in students' education. As a result, Sophia focused on the "foundations" and felt that students would master application if they pursued further study in this field as the following quote illustrates: "…you don't have time to on top of that to spend weeks trying to give them complex problems and you figure it out. It should come later on. So you teach them the foundation, teach them the textbook, teach them to use the textbook and to recognize that when they go on in later courses, they are going to have to try to do work to try to figure out what they need." As the results from our study suggest, students do not necessarily develop more constructivist beliefs at higher levels of education—perhaps because they are not equipped with the skills or experiences needed to think about statistics in this way in their earlier classes or that courses at the graduate level represent an initial introduction to statistics. As Sophia suggested, students may have different experiences and hold more complex views about statistics as they move beyond introductory courses into more advanced statistics classes. This change may only be evident after multiple courses; whereas in the current study both classes were considered introductory.

In contrast to Sophia's approach, Gilbert appeared to rely on traditional approaches to a greater extent. As noted in his interview, it could very well be that students are simply reluctant to shift their beliefs and expect teachers to teach in traditional ways. Given that these students' experiences in mathematics classroom have likely been predominantly traditional (Muis, 2004), they may have been less receptive or equipped to adapt to deviations from what they expected based on prior academic experiences. It may also be the case that the anxiety students experience at this level of education limits the approaches that a teacher might take to teach statistics. Specifically, step-by-step instruction may help to reduce the anxiety that students experience. If asked to develop their own understanding of statistics, or attempt problems using various methodologies, students' level of anxiety may become too overwhelming for them and limit their ability to learn the content. For example, Gilbert spoke about his decision to reduce group problem-solving activities based on students' negative reactions. He also spoke about students' concerns about failure, which, as he explained, was linked to their previous experiences in math courses. Similarly, the teachers too may feel considerable anxiety when faced with the prospect of teaching students to solve problems without step-by-step direction. As such, more traditional approaches may be adopted to provide a scaffold for students and teachers to alleviate this anxiety. In this way, student beliefs (less constructivist), motivations (self-efficacy), emotions (anxiety), goals (performance-approach) and instructional preferences (traditional) may also contribute to the epistemic climate through their engagement level, feedback, and apprehensions, which in turn, may have influenced the course of belief change. For example, it may be the case that although students initially held beliefs about statistics that were more constructivist, self-efficacious, and highly valued, these beliefs diminished if they struggled to adapt to constructivism in practice or if the course material became too challenging. As such, the instructor's change in pedagogical approach can be viewed as responsive and potentially beneficial for this specific class. Generally speaking, the instructor may have been inclined to enact more constructivist practices, but for this particular group of students, the instructor may have opted for more traditional practices given the unique qualities and concerns of the students.

Beyond instructor practices and students factors, there are other differences in course structure that may have contributed to epistemic climate; most notably, the nature of assessments and assignments. For example, in terms of assessment, in Sophia's class, assignments carried a greater weight than exams towards the final grade, whereas in Gilbert's class, exams carried a greater weight than assignments. As Gilbert noted, in the future, he planned to give more weight to assignments given students' performance anxiety about exams. The nature of assignments may also have been related to students' beliefs about statistics. For example, students in Sophia's course were required to complete a final assignment that involved generating research questions of personal interest and collecting their own data for analyses, whereas this type of inquiry-based assignment was not implemented in Gilbert's course. In addition, Sophia noted that 30-45 minutes were reserved at the end of each class to allow students to work on assignments with her guidance. Taken together, these differences in assessment and assignments may have contributed to differences in epistemic climate beyond classroom practices.

4.2. Theoretical Implications

From a theoretical standpoint, these results have important implications for frameworks that describe how students' beliefs develop and shift over time. In particular, as Muis, Bendixen, and Haerle (2006) described, individuals' beliefs are complex and socially constructed; that is, individuals actively construct or make meaning of their experiences, and development of beliefs occurs as a function of one's interactions with the social world (Baxter Magolda, 2004; Belenky, Clinchy, Goldberger, & Tarule, 1986; Bendixen & Rule, 2004; Hofer & Pintrich, 1997). Within this broader context, the development of beliefs begins at birth and continues to develop until the end of life. The commencement of education initiates the development of more specific beliefs about the academic context, which are also socially constructed and context bound. The academic context is also situated within the socio-cultural context, both of which are reciprocally influential. Importantly, Muis *et al*. propose that domain-specific beliefs, like beliefs about statistics, are derived primarily from the instructional context.

Similar to this perspective on the development of beliefs, mathematics educators also agree that the formal mathematics education students receive has a major influence on their beliefs about mathematics. For example, interactionist perspectives assume that culture and social processes are integral to mathematics activity. As Bauersfeld (1993) noted:

> *Participating in the process of a mathematics classroom is participating in a culture of using mathematics, or better: a culture of mathematizing as a practice. The many skills, which an observer can identify and will take as the main performance of the culture, form the procedural surface only. These are the bricks for the building, but the design for the house for mathematizing is processed on another level. As it is with cultures, the core of what is learned through participation is when to do what and how to do it*. (p. 4)

Taken from this view, the development of individuals' analytic and logical processes cannot be separated from their participation in the interactive constitution of taken-as-shared mathematics meanings. Thus, individuals are believed to develop their personal understandings and beliefs about mathematics as they participate in negotiating classroom norms specific to mathematics (Yackel & Cobb, 1996).

Results from our study support these views with regard to how beliefs may develop over time. In particular, the classroom epistemic climate in Sophia's class was inferred to be more mixed with regard to both traditional, teacher-centered approaches to teaching coupled with more constructivist, student-centered approaches. Given that students' beliefs were also mixed, we view this consistency between students' beliefs and the epistemic climate as one that would support students' currently espoused beliefs. To the contrary, Gilbert's students' beliefs were not consistent with the epistemic climate of their classroom. Rather, students initially espoused more constructivist beliefs and shifted toward more traditional views by the end of the semester—perhaps in part due to the more traditional instructional techniques that were used. Consistent with Muis *et al*.'s (2016) framework, these patterns of relations between the epistemic climate and beliefs suggest that the instructional approach (a facet of the educational environment) plays an important role. These findings suggest that the degree of alignment between beliefs and instructional approach may provide an impetus for stability and change. To advance work in this area, theories should account for alignment between students existing beliefs and instructional approaches, as well as explore how the instructional approach using multiple data channels (e.g., self-report, observations, interviews) as our findings suggest that there may be subtle, yet important, divergences across these facets. Interestingly, our results suggest that a boundary for constructivist belief development may be reached when both students and the instructional approach are aligned, as appeared to be the case for Sophia's class. To foster continued belief development, it may require a more thorough integration of constructivist practices along multiple facets of the environment. Given that research has found more positive motivational and learning outcomes when more constructivist approaches are used (Muis, 2004; Muis & Duffy, 2013), it is worthwhile to consider how instructors might approach teaching to further foster constructivist beliefs. We present some pedagogical recommendations next by taking into consideration the data collected from this study (e.g., observations, instructor interviews) and recent empirical work describing interventions that aim to promote more constructivist beliefs.

4.3. Recommendations for Practice

There are several ways that instructors could engage in more constructivist practices within statistics classrooms. The findings from our research offer some insights; however, we also provide suggestions for additional constructivist instructional approaches that could be used to complement the practices we observed in this study based on Muis and Duffy's (2013) findings from recent work in this area. To begin, although both instructors in this study emphasized the importance of interpretation and application for statistics, they did not discuss alternate methods, solutions, or interpretations with the students. One approach may be to present students with a problem and evaluate whether different approaches could be used to solve the problem. Instructors could also present groups of students with a problem that leads to different solutions depending on the analytic approach employed. By discussing the different approaches and possible interpretations with the class, these types of activities may highlight that statistics knowledge is tentative, rather than fixed, and that knowledge is created based on the justification for the methods they select and the interpretations they form (Muis & Duffy, 2013).

Moreover, throughout the course, instructors could discuss unresolved issues and debates about the use of statistical approaches in the field. These types of practices may help to illustrate to students that although there are aspects of statistics that are accepted as true, knowledge in the field continues to evolve and new methods continue to be generated (Muis & Duffy, 2013). To promote constructivism in the classroom, instructors could also directly explain why students should not rely solely on textbooks or instructors for verification of the correct answer. Instructors could encourage students to justify a solution based on the information used to solve the problem. This could involve a class exercise in which students are asked to justify their solutions by providing evidence to support their approach. These types of practices may promote constructivism by encouraging students to justify knowledge through individual opinion and personal experience (Muis & Duffy, 2013).

Despite the potential advantages of these constructivist techniques, we acknowledge that fostering more constructivist beliefs is not simply a matter of prescribing specific instructional practices. On the contrary, the findings from this research suggest that it is also important to acknowledge the potential interaction between students' emotions and prior learning experiences when interpreting the effectiveness of constructivist practices. For instance, the novelty of constructivist methods may be intimidating for some students—particularly those with low self-efficacy and high performance anxieties—and may relate to the course of belief change. Furthermore, as Windschitl (2002) notes, there are several barriers to successfully enacting constructivist practices, such as broader cultural and political considerations (e.g., pressures and expectations from stakeholders and administrators).

It is also worthwhile to note that the instructors in this study produced their own ideas during the interviews to employ more constructivist classroom practices in the future. For example, Sophia discussed the idea of using statistics examples that were tailored to domains of interest for students and developing an assignment that required students to teach a peer about a concept in statistics and play the role of the instructor, because, as she explained: "the best way to learn is to actually teach it to somebody else." Similarly, Gilbert suggested placing more weight on assignments than exams and creating an assignment that required students to generate their own research questions and communicate their plan for statistical analyses by applying concepts covered in the course. He also suggested using more "simulator" based graphical representations that could be manipulated to illustrate key concepts (e.g., visual differences between strong versus weak correlations). Thus, upon reflection, both instructors generated ideas for creating more constructivist-oriented activities within their respective classes. With additional supports, these teachers may be able to more fully align their beliefs with their educational practices. Although these findings have important implications for pedagogy, it is important to bear in mind the limitations of this research, which we address in the following section, along with recommendations for future directions.

4.4. Limitations and Future Directions

In the study we explored relations between epistemic climate and students' beliefs using a mixed-methods approach. Given this, it should be noted that results from the qualitative data are not intended to generalize to all statistics instructors or learning environments. Instead, the goal of the observational and interview data was to provide a more nuanced analysis of instructors' beliefs and classroom practices to help us better understand variations in epistemic climate. In this way, the qualitative data builds on previous work by helping us to interpret and expand on quantitative results. Another limitation is that our research does not directly test mechanisms responsible for shifts in students' beliefs at a micro-level of analysis. Thus, questions of how or when a shift in beliefs occurs among individuals are not fully addressed here. For instance, in addition to epistemic messages embedded through instruction, there are several learner characteristics, such as motivation and depth of processing that likely influence change over time (Dole & Sinatra, 1998). Further, the catalyst for a shift in beliefs may be contingent upon individuals' dissatisfaction with current beliefs as well as perceived value of endorsing new beliefs (Pintrich, Marx, & Boyle, 1993). Thus, additional research is needed to test interactions between cognitive, motivational and social processes involved in belief change.

As a shift in beliefs was detected between the two groups on only one scale dimension, it may be the case that there are certain facets of beliefs about statistics that are more susceptible to change than others. Given that observed and reported differences in instructional approach were nuanced when comparing the two environments, it may also the case that the scale measuring students' beliefs about instruction was not sensitive enough to detect these distinctions. Findings from the qualitative results suggest that self-report measures could be improved to more accurately measure students' beliefs, particularly given that low reliabilities are common within belief research (DeBacker, Crowson, Beesley, Thoma, & Hestevold, 2008; Schraw & Olafson, 2008). In addition, we suggest that future work examine differences among a larger number of students and classes given that the quantitative analyses in this study (factorial ANCOVA) was limited by the small sample size.

Finally, as previously noted, various student-related variables (e.g., emotions) and environmental constraints (e.g., required curriculum, evaluation methods) may also contribute to the epistemic climate and influence the degree to which constructivist approaches foster belief change. As such, it is not our intention to claim that traditional teacher-directed approaches to instruction no longer have any place in education or that they operate within a vacuum. In addition, given that we examined statistics beliefs within the context of social sciences, further work is needed to examine whether these findings can be replicated for statistics classes within other domains (e.g., physics) and how differences in instructional approaches interact with these student and context-specific factors. In a similar vein, the data in this study were collected from two separate schools and, as such, belief differences across classrooms may have been influenced by the broader academic culture of the school environment within which they operated. In this study, we did not examine the nature of school environments in detail as our goal was to examine the more proximal relations between epistemic climate in the classroom and students' beliefs about statistics. Further work is a needed to directly measure contextual influences at multiple levels of analyses (school, classroom, domains).

Despite these limitations, we feel that this research provides meaningful insights into the relationship between epistemic climate and students' beliefs in the context of statistics classrooms. More specifically, our findings provide evidence to suggest that variations in instructional approaches are related to student beliefs and represent an important step toward examining the role of epistemic climate. To expand on this work, we encourage researchers to examine whether other elements of the epistemic climate. In this regard, the application of theoretical models from the conceptual change literature and the use of experimental research designs may provide fruitful avenues for further empirical scrutiny of these processes in an effort to better understand the role of epistemic climate in belief development.

Acknowledgement

Support for this research was provided by a grant to Krista R. Muis, recipient of the Early Career Research Award, from the American Psychological Association.

References

[1] Alexander, P. A., Schallert, D. L., & Hare, V. C. (1991). Coming to terms: How researchers in learning and literacy talk about knowledge. *Review of Educational Research*, *61*(3), 315-343. doi: 10.3102/00346543061003315

[2] Bauersfeld, H. (1993). *Teachers' pre- and in-service education for mathematics teaching.* Seminaire sur la Representation, No.78. Montreal: University of Quebec.

[3] Baxter Magolda, M. B. (2004). Evolution of a constructivist conceptualization of epistemological reflection. *Educational Psychologist*, *39*(1), 31–42. doi:10.1207/s15326985ep3901_4

[4] Belenky, M. F., Clinchy, B. M., Goldberger, N. R., & Tarule, J. M. (1986). *Women's ways of knowing: The development of self, voice, and mind*. New York: Basic Books Inc.

[5] Bendixen, L. D., & Rule, D. C. (2004). An integrative approach to personal epistemology: A guiding model. *Educational Psychologist*, *39*(1), 69-80. doi:10.1207/s15326985ep3901_7

[6] Boscolo, P., & Mason, L. (2001). Writing to learn, writing to transfer. In P. Tynjala, L. Mason, and K. Lonka (Eds.), *Writing as a learning tool: Integrating theory and practice* (pp.83–104). Dordrecht, The Netherlands: Kluwer Academic Press.

[7] Buehl, M. M., & Fives, H. (2009). Exploring teachers' beliefs About teaching knowledge: Where does it come from? Does it change? *The Journal of Experimental Education*, *77*(4), 367-408. doi:10.3200/JEXE.77.4.367-408

[8] Cheng, M. M. H., Chan, K.-W., Tang, S. Y. F., & Cheng, A. Y. N. (2009). Pre-service teacher education students' epistemological beliefs and their conceptions of teaching. *Teaching and Teacher Education*, *25*(2), 319–327. doi:10.1016/j.tate.2008.09.018

[9] Chi, M. T. H. (1997). Quantifying qualitative analyses of verbal data: A practical guide. *Journal of the Learning Sciences, 6*(3), 271-315. doi:10.1207/s15327809jls0603_1

[10] Cobb, P. (1994). Where is the mind? Constructivist and sociocultural perspectives on mathematical development. *Educational Researcher*, *23*(7), 13–20. doi:10.3102/0013189X023007013

[11] Cobb, P., & Yackel, E., (1996). Constructivist, emergent, and sociocultural perspectives in the Context of development research. *Educational Psychologist*, *31*(3-4), 175-190, doi:10.1080/00461520.1996.9653265

[12] Creswell, J. W. (2007). *Qualitative inquiry and research design: Choosing among five approaches* (2nd ed.). Thousand Oaks, CA: Sage.

[13] DeBacker, T. K., Crowson, H. M., Beesley, A. D., Thoma, S. J., & Hestevold, N. L. (2008). The challenge of measuring epistemic beliefs: An analysis of three self-report instruments. *The Journal of Experimental Education*, *76*(3), 281-312. doi:10.3200/JEXE.76.3.281-314

[14] De Corte, E., Op't Eynde, P., & Verschaffel, L. (2002). ''Knowing what to believe'': The relevance of students' mathematical beliefs for mathematics education. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 297–320). Mahwah, NJ: Erlbaum.

[15] Dole, J. A., & Sinatra, G.M. (1998). Reconceptalizing change in the cognitive construction of knowledge. *Educational Psychologist*, *33*(2-3), 109–128. doi:10.1080/00461520.1998.9653294

[16] Fang, Z. (1996). A review of research on teacher beliefs and practices. *Educational Research*, *38*(1), 47-65. doi:10.1080/0013188960380104

[17] Feucht, F. C. (2010). Epistemic climate in elementary classrooms. In L. D. Bendixen & F. C. Feucht (Eds.), *Personal epistemology in the classroom: Theory, research, and implications for practice* (pp. 55–93). New York, NY: Cambridge University Press.

[18] Fives, H., & Buehl, M. M. (2008). What do teachers believe? Developing a framework for examining beliefs about teachers' knowledge and ability. *Contemporary Educational Psychology*, *33*(2), 134–176, doi:10.1016/j.cedpsych.2008.01.001

[19] Fives, H., & Buehl, M. M. (2012). Spring cleaning for the "messy" construct of teachers' beliefs: What are they? Which have been examined? What can they tell us? In K. R. Harris, S. Graham, & T. Urdan (Eds.), *APA educational psychology handbook* (Vol. 2, pp.471-499). Washington, DC: American Psychological Association. doi:10.1037/13274-019

[20] Garofalo, J. (1989). Beliefs and their influence on mathematical performance, Mathematics Teacher, *82*(7), 502-505.

[21] Haerle, F. C., & Bendixen, L. D. (2008). Personal epistemology in elementary classrooms: A conceptual comparison of Germany and the United States and a guide for future cross-cultural research. In M. S. Khine (Ed.), *Knowing, knowledge and beliefs: Epistemological studies across diverse cultures* (pp. 151–176). Dordrecht, the Netherlands: Springer-Verlag.

[22] Higgins, J. J. (1999). Nonmathematical statistics: A new direction for the undergraduate discipline. *The American Statistician*, *53*(1). 1-6, doi:10.2307/2685641

[23] Higgins, K. M. (1997). The effect of year-long instruction in mathematical problem solving on middle-school students' attitudes, beliefs, and abilities. *The Journal of Experimental Education*, *66*(1), 5–28. doi:10.1080/00220979709601392

[24] Hofer, B. K. (1999). Instructional context in the college mathematics classroom: Epistemological beliefs and student motivation. *Journal of Staff, Program, & Organizational Development*, *16*(2), 73–82.

[25] Hofer, B. K. (2000). Dimensionality and disciplinary differences in personal epistemology. *Contemporary Educational Psychology*, *25*(4), 378-405. doi:10.1006/ceps.1999.1026

[26] Hofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research*, *67*(1), 88–140, doi:10.3102/00346543067001088

[27] Johnston, P., Woodside-Jiron, H., & Day, J. (2001). Teaching and learning literate epistemologies. *Journal of Educational Psychology*, *93*(1), 223–233. doi:10.1037/0022-0663.93.1.223

[28] Kane, R., Sandretto, S., & Heath, C. (2002). Telling half the story: A critical review of research on the teaching beliefs and Practices of university academics. *Review of Educational Research*, *72*(2), 177-228. doi:10.3102/00346543072002177

[29] Kang, N-H., & Wallace, C. S. (2005). Secondary science teachers' use of laboratory activities: Linking epistemological beliefs, goals, and practices. *Science Education*, *89*(1), 140-165. doi:10.1002/sce.20013

[30] Kline, R. B. (1998). *Principles and practice of structural equation modeling*. New York: The Guilford Press.

[31] Kloosterman, P. (1996). Students' beliefs about knowing and learning mathematics: Implications for motivation. In M. Carr (Ed.), *Motivation in mathematics* (pp. 131-156). Cresskill, NJ: Hampton Press.

[32] Kloosterman, P., & Cougan, M. C. (1994). Students' beliefs about learning school mathematics. *Elementary School Journal*, *94*(4), 375-388.

[33] Lampert, M. (1990). When the problem is not the question and the solution is not the answer: Mathematical knowing and teaching. *American Educational Research Journal*, *27*(1), 29–63, doi:10.3102/00028312027001029

[34] Levitt, K. E. (2002). An analysis of elementary teachers' beliefs regarding the teaching and learning of science. *Science Education*, *86*(1), 1–22, doi:10.1002/sce.1042

[35] Lidar, M. Lundqvist, E., & Ostman, L. (2006). Teaching and learning in the science classroom: The interplay between teachers' epistemological moves and students' practical epistemology. *Science Education*, *90*(1), 148-163, doi:10.1002/sce.20092

[36] Louca, L., Elby, A., Hammer, D., & Kagey, T. (2004). Epistemological resources: Applying a new epistemological framework to science instruction. *Educational Psychologist*, *39*(1), 57–68. doi:10.1207/s15326985ep3901_6

[37] Maggioni, L., & Parkinson, M. M. (2008). The role of teacher epistemic cognition, epistemic beliefs, and calibration in instruction. *Educational Psychology Review*, *20*(4), 445-461. doi:10.1007/s10648-008-9081-8

[38] Marshall, H. H. (1996). Implications of differentiating and understanding constructivist approaches. *Educational Psychologist*, *31*(3-4), 235-240, doi:10.1080/00461520.1996.9653270

[39] McLeod, D. B. (1992). Research on affect and mathematics education: A reconceptualization. In D. A. Grouws (Ed.), *Handbook of research on mathematics teaching and learning* (pp. 575–596). New York: Macmillan.

[40] Moore, D. S. (1997). New pedagogy and new content: The case of statistics. *International Statistical Review*, *65*(2), 123-137. doi:10.1111/j.1751-5823.1997.tb00390.x

[41] Muis, K. R. (2004). Personal epistemology and mathematics: A critical review and synthesis of research. *Review of Educational Research*, *74*(3), 317-377. doi:10.3102/00346543074003317

[42] Muis, K. R. (2008). Epistemic profiles and self-regulated learning: Examining relations in the context of mathematics problem solving. *Contemporary Educational Psychology*, *33*(2), 177–208, doi:10.1016/j.cedpsych.2006.10.012

[43] Muis, K. R., Bendixen, L. D., & Haerle, F. C. (2006). Domain-generality and domain-specificity in personal epistemology research: Philosophical and empirical reflections in the development of a theoretical framework. *Educational Psychology Review*, *18*(1), 3–54. doi:10.1007/s10648-006-9003-6

[44] Muis, K. R., & Duffy, M. C. (2013). Epistemic climate and epistemic change: Instruction designed to change students' beliefs and learning strategies and improve achievement. *Journal of Educational Psychology*, *105*(1), 213-225. doi:10.1037/a0029690

[45] Muis, K. R., & Foy, M. J. (2010). The effects of teachers' beliefs on elementary students' beliefs, motivation, and achievement in mathematics. In L. D. Bendixen & F. Feucht (Eds.), *Personal epistemology in the classroom: Theory, research, and implications for practice*. (pp. 435-469). New York, NY: Cambridge University Press.

[46] Muis, K. R., Trevors, G., & Chevrier, M. (2016). Epistemic climate for epistemic change. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *Handbook of epistemic cognition* (pp. 331-359). New York, NY: Routledge.

[47] Murphy, P. K., Alexander, P. A., & Muis, K. R. (2012). Knowledge and knowing: The journey from philosophy and psychology to human learning. In K. R. Harris, S. Graham, T. Urdan, C. B. McCormick, G. M. Sinatra, & J. Sweller (Eds.), *APA Educational Psychology Handbook ─ Vol. 1: Theories, constructs, and critical issues* (pp.189-266). Washington, DC: American Psychological Association. doi:10.1037/13273-008

[48] National Council of Teachers of Mathematics (NCTM). (1989). *Curriculum and evaluation standards for school mathematics*. Reston, VA: NCTM.

[49] National Council of Teachers of Mathematics (NCTM). (2010). *Mathematics education organizations unite to support implementation of common core state standards*. Reston, VA: Author.

[50] National Research Council. (1989). *Everybody counts: A report to the nation on the future of mathematics education.* Washington, DC: National Academy Press. doi:10.17226/1199

[51] Olafson, L., & Schraw, G. (2006). Teachers' beliefs and practices within and across domains. *International Journal of Educational Research*, *45*(1-2), 71–84. doi:10.1016/j.ijer.2006.08.005

[52] Olafson, L., Schraw, G., & Veldt, M. V. (2010). Consistency and development of teachers' epistemological and ontological world views. *Learning Environments Research*, *13*(3), 243-266. doi:10.1007/s10984-010-9078-3

[53] Op't Eynde, P., & De Corte, E. (2003). *Student's mathematics-related belief systems: Design and analysis of a questionnaire.* Paper presented at the Annual Meeting of the American Educational Research Association, Chicago, 21-25 April.

[54] Pajares, M. F. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. *Review of Educational Research*, *62*(3), 307-332. doi:10.3102/00346543062003307

[55] Perry, B., Tracey, D., & Howard, P. (1999). Head mathematics teachers' beliefs about the learning and teaching of mathematics. *Mathematics Education Research Journal*, *11*(1), 39-53. doi:10.1007/BF03217349

[56] Pintrich, P. R. (2002). Future challenges and directions for theory and research on personal epistemology. In B. K. Hofer, & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 389–414). Mahwah, NJ: Erlbaum.

[57] Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research*, *63*(2), 167-199. doi:10.3102/00346543063002167

[58] Powell, R. R. (1996). Epistemological antecedents to culturally relevant and constructivist classroom curricula: A longitudinal study of teachers' contrasting world views. *Teaching and Teacher Education*, *12*(4), 365-384. doi:10.1016/0742-051X(95)00048-O

[59] Prawat, R. S. (1996). Constructivism, modern and postmodern. *Educational Psychologist, 31*(3-4), 215-225. doi:10.1080/00461520.1996.9653268

[60] Rolka, K., & Bulmer, M. (2005). Picturing Student Beliefs in Statistics. *ZDM*, *37*(5), 412-417. doi:10.1007/s11858-005-0030-4

[61] Schoenfeld, A. H. (1985). *Mathematical problem solving*. New York: Academic Press.

[62] Schoenfeld, A. H. (1989). Explorations of students' mathematical beliefs and behavior. *Journal for Research in Mathematics Education*, *20*(4), 338–355. doi:10.2307/749440.

[63] Schraw, G., & Olafson, L. (2003). Teachers' epistemological world views and educational practices. *Journal of Cognitive Education and Psychology*, *3*(2), 178-235. doi:10.1891/194589503787383109

[64] Schraw, G. J., & Olafson, L. J. (2008). Assessing teachers' epistemological and ontological worldviews. In M. S. Khine (Ed.), *Knowing, knowledge and beliefs: Epistemological studies across diverse cultures* (pp. 25–44). New York, NY: Springer. doi: 10.1007/978-1-4020-6596-5

[65] Smith, C. L., Maclin, D., Houghton, C., & Hennessey, M. G. (2000). Sixth-grade students' epistemologies of science: The impact of school science experiences on epistemological development. *Cognition and Instruction*, *18*(3), 349–422, doi:10.1207/S1532690XCI1803_3

[66] Thompson, A. (1992). Teachers' beliefs and conceptions: A synthesis of the research. In D. A. Grouws (Ed.), *Handbook of research on mathematics teaching and learning* (pp.127-146). New York: Macmillan.

[67] Verschaffel, L., De Corte, E., Lasure, S., Van Vaerenbergh, G., Bogaerts, H., & Ratinckx, E. (1999). Learning to solve mathematical application problems: A design experiment with fifth graders. *Mathematical Thinking and Learning*, *1*(3), 195–229. doi:10.1207/s15327833mtl0103_2

[68] Voigt, J. (1995). Thematic patterns of interaction and sociomathematical norms. In P. Cobb & H. Bauersfeld (eds.), *The emergence of mathematical meaning: Interaction in classroom cultures* (pp.163-202). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

[69] White, B. C. (2000). Pre-service teachers' epistemology viewed through perspectives on problematic classroom situations. *Journal of Education for Teaching*, *26*(3), 279–305.

[70] Windschitl, M. (2002). Framing constructivism in practice as the negotiation of dilemmas: An analysis of the conceptual, pedagogical, cultural, and political challenges facing teachers. *Review of Educational Research*, *72*(2), 131–175. doi:10.3102/00346543072002131

[71] Windschitl, M., & Andre, T. (1998). Using computer simulations to enhance conceptual change: The roles of constructivist instruction and student epistemological beliefs. *Journal of Research in Science Teaching*, *35*(2), 145–160. doi:10.1002/(SICI)1098-2736(199802)35:2<145::AID-TEA5>3.0.CO;2-S

[72] Yackel, E., & Cobb, P. (1996). Sociomathematical norms, argumentation, and autonomy in mathematics. *Journal for Research in Mathematics Education*, *27*(4), 458–477. doi:10.2307/749877