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CONNECTING DISCIPLINARY AND PEDAGOGICAL SPACES IN STATISTICS:

PERSPECTIVES FROM GRADUATE TEACHING ASSISTANTS

By

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ABSTRACT

As a young and dynamically evolving discipline, statistics evokes many conceptions about its purpose, the nature of its development, and the tools and mindset needed to engage in statistical work. While much research documents the perceptions of statisticians on these matters, little is known about how the disciplinary perspectives of statistics instructors may interact with the work of teaching. Such connections are likely relevant since research has shown that teachers' and instructors' views about the discipline they teach inform their instructional approaches. This work specifically focuses on the disciplinary views of graduate teaching assistants (GTAs), who continue to serve a critical role in undergraduate instruction. Using multiple case study design, I document the views, experiences, and teaching practices of four statistics GTAs over the course of a full year—from their induction into the department in the fall, until their first solo-teaching opportunity the following summer.

From the literature, I organized important disciplinary themes in statistics, including disciplinary purpose, epistemology, and disciplinary engagement. Targeting issues and questions stemming from these areas, I documented the various perspectives, models, and tensions that characterized the disciplinary views of the participants. I also documented the relevant experiences and influences that motivated these views. Additionally, I explored the GTAs' pedagogical views and vision for teaching introductory statistics while looking for possible connections (and glaring disconnects) between these views and their disciplinary views. Finally, I observed their instruction and considered the participants' teaching reflections as I looked for alignment between their expressed views and actual instructional decisions.

My analysis revealed that several of the GTAs expressed sophisticated views and expert notions about the discipline. There was, however, a clear disconnect between their perceptions of

disciplinary work and the work of students in an introductory statistics course. Despite recognition that statistical questions typically do not have right answers, that statistical methods are often quite flexible and contextually-driven, or that many disciplinary elements developed through community negotiation rather than discovery, the GTAs struggled to bridge these considerations to the tasks being posed and the practices being emphasized in introductory courses. The participants also expressed a basic desire to engage students in practice problems and activities, yet their instructional visions were not specific and well-grounded in rich classroom experiences that modeled student-centered pedagogy. As a result, all four GTAs converged on a singular vision for introductory statistics. This vision involved focusing on "the basics," acquainting students with a wide array of procedures, honing students' computational abilities, and emphasizing statistical problem-solving as a pursuit for right answers.

This dissertation study provides insights into disciplinary tensions that may be of value in developing an instrument for assessing the disciplinary views of instructors and students alike. GTAs without well-developed views may need opportunity to engage in rich, open-ended tasks that serve to develop their disciplinary perspectives. Additionally, this work reveals how GTAs may struggle to bridge their perceptions of advanced disciplinary work to the work of their own students. Acquaintance and experience engaging in tasks that promote informal inferential reasoning or exploratory data analysis, coupled with connections to situated and constructivist learning theories, may enrich GTAs' instructional visions as they see how disciplinary and instructional spaces may interact and inform one another.

CHAPTER 1

INTRODUCTION

Statement of the Problem

With a growing number of business sector positions requiring experience in statistics and data analytics (Bureau of Labor Statistics, 2014; Manyika et al., 2011), educational reform efforts are tuned to addressing the quality of statistics instruction at all levels (American Statistical Association [ASA], 2005, 2016; National Council of Teachers of Mathematics [NCTM], 2013). The elevated importance of statistics as a critical, interdisciplinary tool has led to increasing numbers of undergraduate students from all disciplines taking introductory level courses (Blair, Kirkman, & Maxwell, 2013).

Graduate teaching assistants (GTAs) play a key role in undergraduate statistics instruction. According to a report by Blair and colleagues (2013), GTAs served as instructors of record for an estimated 24% of non-calculus-based courses in statistics departments and 28% of the same courses in mathematics departments in 2010; this was in addition to GTAs serving as recitation/lab instructors and graders. Unfortunately, GTAs often receive little formal preparation for teaching (Moore, 2005; Speer Gutmann, & Murphy, 2005). GTA preparation within mathematical disciplines in general is typically short and often focused on covering administrative details, allowing only for brief, superficial opportunities for participants to practice and reflect on their teaching (Shannon, Twale, & Moore, 1998; Speer et al., 2005).

The sparse research on statistics GTAs finds that many have limited conceptual understanding of the introductory course content they are asked to teach (Dolor, 2017; Green & Blankenship, 2014; Noll, 2011). Such realities may not be surprising when one considers that many doctoral statistics programs may not require newly admitted students to have previous coursework in research design or introductory applied statistics. In addition, once in the program, these students begin to take graduate courses thatmay emphasize statistics through a mathematical, theoretically-dense lens. As a result, statistics GTAs may not have a substantive curricular vision for the goals of an *introductory* statistics course (Green, 2010; Noll, 2011).

Purpose

As a recently established field of scholarship, statistics education still encompasses many under-developed areas of research. The field knows little about effective professional development practices for statistics instructors at the undergraduate level, including GTAs (Pearl et al., 2012). This gap in the research is compounded by the reality that statistics is an evolving discipline; the emergence of data science and growing accessibility and inundation of data bring new pedagogical challenges (ASA, 2015; 2016; Johnson & Gluck, 2016). As the field continues to move forward, undergraduate statistics instruction runs the risk of falling behind.

GTAs represent a unique and diverse group of instructors: since many GTAs are also enrolled in their own coursework, they have the dual perspective of being both a student and instructor. Furthermore, these students may be recruited from varied academic backgrounds and nationalities (National Science Foundation [NSF], 2002), meaning their familiarity, experience, and understanding of statistics content may differ widely. As undergraduate instructional needs grow, many large universities will likely increase their dependence on GTAs. Subsequently, research is needed that explores how to train and support them effectively while leveraging the distinct backgrounds and expressed views of GTAs.

My research interests are primarily inspired by my own personal and professional experiences (Corbin & Strauss, 2008), having once been a statistics GTA myself. By wrestling with many questions about the purpose of an introductory statistics course and the nature of statistics as a discipline, I recognized my own conceptions were greatly changing and adapting based on new experiences. Furthermore, my changing conceptions were motivating a new vision for teaching introductory statistics. In this dissertation, I seek to understand how GTAs develop a vision for statistics pedagogy by examining the disciplinary perspectives and background experiences that contribute to this developing classroom vision. Without awareness of GTAs' initial views, departments will no doubt struggle to prepare new GTAs constructively to teach introductory courses according to the principles outlined in the Guidelines for Assessment and Instruction in Statistics Education (GAISE) College Report.

In this work, I first develop a framework for understanding the core disciplinary perspectives and tensions with which first-year statistics GTAs grapple. Building from related research on the topic (e.g., Diamond & Stylianides, 2017; Hofer & Pintrich, 1997; Op ‘t Eynde, De Corte, & Verschaffel, 2006; Schoenfeld, 1992; Tsai & Liu, 2005), I present four dimensions that represent different facets of these disciplinary views. I argue that understanding these fundamental perspectives serves as a precursor to understanding how new GTAs think about the goals of statistics instruction. With this knowledge, statistics educators will be better positioned to support GTAs in understanding and adopting reform-oriented pedagogical views.

My second goal in this work is to understand the experiences, disciplinary views, and pedagogical views of four first-year statistics GTAs through a multiple-case-study lens (Yin, 2009). I share detailed examples of how their disciplinary views emerge and in what ways these disciplinary views relate to their developing instructional vision for introductory statistics.

Finally, I investigate the participants' teaching practices to see how the views and perspectives they articulate during their first two semesters as GTAs interact (or fail to interact) with their instructional decisions. This investigation also considers other factors at play in the enactment of each GTA’s course and whether these factors are at odds with their personal perspectives and views. Based on these findings, I offer recommendations for effective instructional training for statistics GTAs. I summarize my dissertation goals through the following research questions:

1. How might a framework be used to organize the various disciplinary perspectives and tensions that first-year statistics GTAs grapple with?
2. What are the specific disciplinary views of each of these four first-year GTAs? How do their varied experiences relate to their individual disciplinary views?
3. How do their disciplinary views relate to and inform their pedagogical views for an introductory statistics course? What other influences inform their pedagogical views?
4. How do their disciplinary views relate to and inform their instructional decisions and practices? What other influences inform their instructional decisions and practices?

Researcher Bias

To undertake this study with credibility and transparency, I needed to be aware of my own experiences, disciplinary views, and vision for teaching statistics (Guba & Lincoln, 1994). This work stems in part from my own personal reflections as a former statistics GTA. With mathematical statistics as the epitome of my statistical coursework as an undergraduate student in mathematics, I began a PhD program in statistics with little understanding of the practice of doing statistics. My conceptual understanding of introductory level content was initially weak, developing in a topic-wise fashion while I worked as a recitation instructor. It was not until I engaged in course planning before my first solo teaching assignment that I first made sense of statistical inference beyond procedures. I found teaching was the bridge that helped me see statistics in terms of a larger, conceptual picture. My motivation to learn was based on my desire to be a better teacher and my developing identity as a statistics educator. However, I recognize my experience does not generalize to all or even most statistics GTAs; therefore, I am engaging in this research to understand others' personal stories with the assumption that there are many other stories to tell.

I originally entered my statistics degree program with objective, static conceptualizations about the nature of both mathematics and statistics. I viewed statistical work as objective, computational, and as the direct application of mathematics. With procedural tasks, theoretically-dense lectures, and mathematical calculations as my pre-teaching experience with statistics, it was my own personal studies that ultimately led me to question my disciplinary views; I began to see statistical formulas not as right and wrong, but as contextually-valid, constructed, and socio-culturally dependent (Diamond & Stylianides, 2017). Statistics was no longer simply a body of knowledge or a collection of formulas, but a creative activity. As a pianist who has studied and participated in the fine arts extensively, it was revolutionary for me to discover striking commonalities between musical creativity and the analytical skills I now used to explore data.

I now think of statistics as the art of quantitatively representing and making sense of the world. I see the justification for statistics as a discipline being found in humanity's widespread encounters with variability in the world and our attempts to capture and understand this variability with data. As such, in my pursuit to understand the disciplinary views of others, I have my own perspective on how statistics should be understood. The temptation for me is to view my own progression in ideas as representing an enlightened path. My research goals are, first and foremost, to report GTAs' views richly and to understand their origin and influence. I do, however, make judgments with respect to the perspectives shared by statisticians and statistics educators in the literature. I primarily assess the value of the participants' views insomuch that they facilitate or cloud their abilities to enact research-based instructional practices in their classrooms, as outlined by the GAISE Report (ASA, 2016).

My own department training experiences and reflections must also be taken into consideration. I had mixed feelings about my department's training program; while some aspects were beneficial to my growth as an instructor, there was a lack of focus on statistics-specific pedagogy. I found many in my department to take up (or fail to take up) the training quite differently. Some GTAs in my department made little effort to improve, expressing little dissatisfaction in their teaching, or being more intrigued with reducing their workload to minimal levels. Other GTAs wanted to be good teachers, but many struggled to develop a robust vision for what good teaching was, or let that desire extinguish after one semester. Others remained consistent in their ambitions to be great teachers and made steady progress each semester. These different responses prompted me to wonder what external or internal factors were influencing these different responses. This study examines how others have responded to various sets of circumstances and initial perspectives as they begin their roles as instructors.

I approached this study seeking to report GTAs' experiences and responses to two different sets of contextual features. The first set are those features that are naturally embedded in the program and relatively unaffected by my presence in this study. For example, the GTA workshop, their experiences before joining the department, and classroom experiences all reflect typical components of any new statistics GTA's journey. I am also introducing a new set of artificial influences by facilitating surveys and interviews. This aspect of the study might be viewed loosely as an intervention, in which the tasks I have GTAs complete, the request for reflection, and the introduction of potentially novel ways of thinking about teaching statistics will provide new experiences that may contribute to their developing vision. I strive to be transparent throughout my analysis and reporting of findings to clarify when certain GTA-expressed views may stem from interventional pieces of this study.

Conceptual Framework

This work documents the journey four statistics GTAs took as they assumed roles and identities as statistics instructors. I view each GTA's development as taking place within an ongoing narrative, comprised of influential experiences before starting the program, experiences as recitation instructors/graders, experiences in department training, experiences as solo-instructors, and experiences as members of a department and GTA community. Each GTA holds a different and nuanced set of views about how introductory statistics should be taught based on their own unique narrative. While I explore these narratives through a multiple case study lens (Yin, 2009), I also think holistically about connections between the participants' disciplinary views and instructional vision. To address these connections, I first discuss two fundamental constructs in my work—experience and views. I then present and discuss a conceptual framework I developed from relevant literature to guide my analysis. Finally, I discuss how this framework informs my investigation of GTAs' pedagogical views and teaching practices.

Constructs.

Experience. Roth and Jornet (2014) explain that experience can be generally described along one of two perspectives. The first perspective is experience as a continuous, steady stream of life lived, which I describe in this work as the participants' *narrative*. The second perspective, which is the definition I use in this work, is *experience* as a singular event or cluster of events of interest in the life of an individual. Roth and Jornet also drew on work from Vygotsky (1935/1994) and Dewey (1938/2008) to present markers signaling that an experience has taken place. Here, I describe three of those markers, which I revisit in my analysis.

First, we can think of experience as taking place in transactions between person and environment. In a conversation or discussion, experience ebbs and flows as thoughts and ideas are shared, carrying momentum and energy. Responses are formulated in the moment, rather than being scripted. Second, experience manifests itself in passions. It involves risk in the sense that it describes our continual venturing into somewhere new and being exposed to the uncertain. As such, having *an* experience is closely associated with having an affective response, where the degree of the affective response signals the meaning and intensity of the experience. Finally, experience is transformative. It is through experience that we learn, grow, and develop. When we think of *an* experience, we typically measure its overall significance in terms of its transformational power.

In applying theories of experience to this study, I note that GTAs come into their assistantships with previous experiences that may shape their current disciplinary and pedagogical conceptions. Additionally, GTAs gather new experiences during their time in the department, such as department training and peer interactions. Unfortunately, most of these experiences go unobserved, meaning I depend on each GTA's recall of experiences in such cases to determine their influence. Interviews allowed me as the researcher to probe and test explanations with participants to better understand the potential power of certain experiences on their disciplinary and pedagogical views.

Views. Much of the literature on GTA training and professional development describes GTAs as holding beliefs, whether those be beliefs about their discipline or about pedagogy. Philipp (2007) describes *beliefs* as often taking the form of premises and propositions based on evidence and experience. In my work, however, I recognize a unique dynamic that takes place with graduate GTAs preparing to be solo teachers that contrasts with the experiences of practicing statisticians, as well as those of in-service (and to some degree pre-service) teachers.

To the first point, first-year statistics graduate students may have little previous coursework in the discipline and possibly no career experience in that field. Additionally, GTAs are not expected to enter their assistantship responsibilities with teaching experience, nor are they entering a teaching-credential program. I question whether many first-year GTAs have had sufficient experiences from which to create a comprehensive set of beliefs about the discipline of statistics and the practices of teaching. Rather, GTAs express many ideas that may be better described as *views*, meaning articulated conceptions of how they think about statistics and descriptions of how they expect to teach based on loosely related experiences, such as their own experiences as students. Munter (2014) argues for this use of *views* rather than *beliefs* to emphasize the lack of solidified experiences or reflexive practice that often serve as the basis for beliefs. That is not to say that all GTAs lack well-developed conceptions about statistics or statistics pedagogy that could be labeled as *beliefs*; I instead offer a broader term in *views* that does not assume a substantive level of reflection. Likewise, I use the term *vision* in the context of teaching to broadly describe views (or beliefs) that look forward. Hammerness (2001) defines *vision* in the context of teaching as “a set of images of ideal classroom practice for which teachers strive” (p. 143).

When seeking to understand teaching practices, different kinds of instructor views need to be considered. Most directly, teaching practice is closely tied to one’s *pedagogical views*: views about curriculum, effective teaching practice, and how students learn (Borko & Putnam, 1996; Remillard, 1999). Statistics instructors’ pedagogical views may be expressed in many ways, including their ideas about how their class should be structured (e.g., lecturing, group activities, example problems, etc.), their goals for students in an introductory course, how assessment is used to assess student knowledge, and other teaching-related ideas they bring to their classroom vision (ASA, 2016).

While pedagogical views are central to understanding teaching practice, research in mathematics and science education has also argued that teachers' instructional decisions are deeply influenced by their views about the nature of the discipline they teach (Abd-El-Khalick, Bell, & Lederman, 1998; Speer, 2008; Thompson, 1984). As a young, multi-faceted discipline (ASA, 2015; De Veaux & Velleman, 2008), statistics proves to be an area ripe for investigation on this matter. For this reason, I first investigate the disciplinary views of statistics instructors (specifically GTAs), followed by findings and discussions on the connection between each participant's disciplinary views, pedagogical views, and teaching practices.

Disciplinary framework for statistics. In considering the various disciplinary dimensions that might be relevant to this discussion in statistics, I considered perspectives from statistics, mathematics, and science. My synthesis of this exploration of the literature yielded four key dimensions that frame this study. They are as follows: The nature of statistics, the nature of statistical knowledge, the nature of knowing statistics, and the nature of doing statistics. These dimensions and several guiding bullet points for each are provided in Figure 1.1. Next, I describe the basis in the literature for each of these dimensions.

The nature of statistics reflects central purposes and distinctions of the discipline. This consideration comes in part from my own beliefs that statistics is a dynamic, multi-faceted body of work with yet evolving purposes. The mathematics education literature highlights purpose as central to understanding views about disciplinary progress (Op 't Eynde, De Corte, & Verschaffel, 2006; Stanic & Kilpatrick, 1989) Op 't Eynde and colleagues define "beliefs about

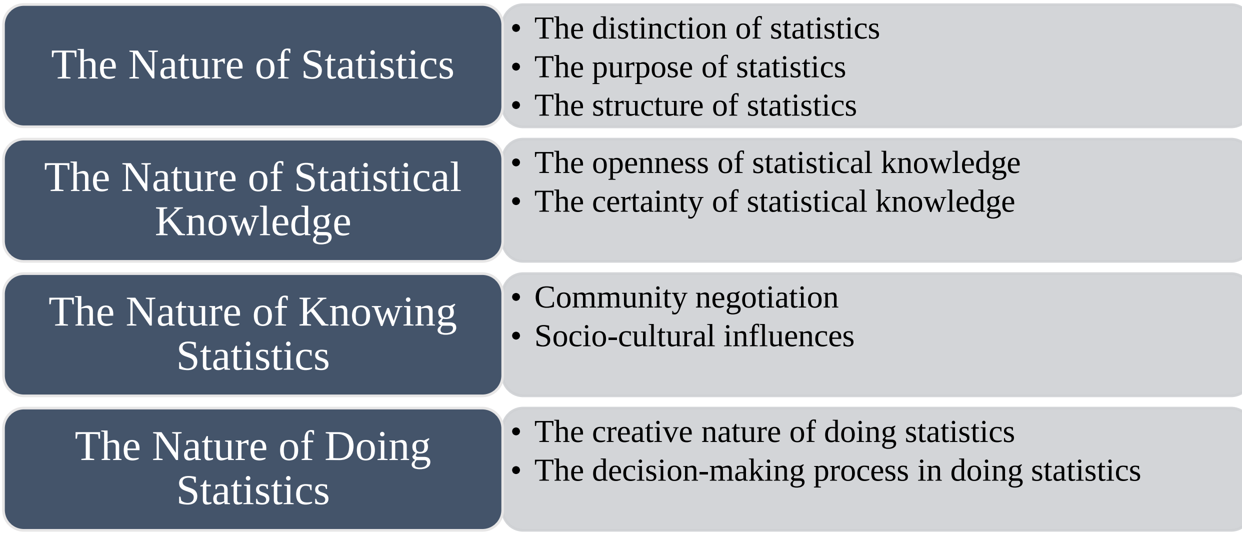

Figure 1.1. Disciplinary Framework for Statistics

self as a mathematician" as a core category in understanding students' disciplinary views towards mathematics, which includes views about intrinsic and extrinsic goals for engaging in mathematical problem solving. Stanic and Kilpatrick identify several of these possible motivations for engaging in problem solving (e.g., as recreation, as practice, as motivation to learn the content, to demonstrate the value of mathematics, etc.).

The second and third dimensions of this framework reference epistemological considerations. One's personal epistemology may be defined as one's beliefs about knowledge and the process of knowing in general (Hofer & Pintrich, 1997). In recent decades, however, researchers have questioned the notion that individuals express holistic commitments that comprehensively reflect their views of knowledge. Instead, researchers are reaching consensus that epistemic views appear more contextual and domain-specific (Buehl, Alexander, & Murphy, 2002; Op 't Eynde et al., 2006). The case for domain-specific lenses on epistemology can be readily made when one considers what is often privileged in different classrooms. In the mathematics classroom, Schoenfeld (1992) noted that it is typical for students to think there is only one right answer and that mathematics is a solitary activity. Contrast this perspective with norms in the Humanities, where students more readily recognize peer review and negotiation as means to developing knowledge (Donald, 1990).

Despite the domain-specific nature of epistemologies, Hofer and Pintrich (1997) and Hofer (2000) proposed that researchers can still identify foundational themes (dimensions) in individual's epistemic views across disciplines. In other words, epistemology across all disciplines can be summarized and structured similarly, but people's specific disciplinary commitments may differ depending on the domain they are asked to think within. Through both their own empirical work with first-year college students and their review of the literature at the time, Hofer and Pintrich offered two broad dimensions as a basis for building an epistemological framework for any field: The nature of knowledge (which can be further broken into the certainty and simplicity of knowledge) and the nature of knowing (further broken into the source of knowledge, justification for knowing, and the attainability of truth). I include these two general dimensions in my framework.

In considering statistics, mathematics, and science education literature, I draw from work by Diamond and Stylianides (2017) to unpack the statistical epistemologies of statistics professors. They borrow from Hofer and Pintrich's (1997) base dimensions while offering insight into key perspectives and tensions that are distinctly statistical. Additionally, Tsai and Liu (2005) offer a view of a scientific epistemology that adds depth to the traditional dimensions proposed by Hofer and Pintrich (1997). Within their five-dimension framework for a scientific epistemology, Tsai and Liu emphasize sociocultural factors that affect the nature and development of scientific knowledge. Findings from these studies influence my work as considerations that inform my interview and task protocols.

The fourth listed dimension, the nature of doing statistics, is also clearly linked and unpacked from the literature. Buehl et al. (2002) and Op ‘t Eynde et al. (2006) propose the nature of problem solving as an important disciplinary consideration. Such considerations have been central to understanding one’s orientation toward mathematics, as suggested by historical and ongoing disagreements over the meanings of terms like *problems* and *problem solving* (Schoenfeld, 1992). Russ (2014) makes a similar case in science, claiming that an epistemology of science should have implications in crafting an epistemology *for* science. In other words, one’s views about how knowledge is constructed in science are closely linked with one’s views about how one engages in scientific work. Tsai and Liu (2005) again offer insights, as their study probed the degree to which participants viewed invention and creativity, stability, and theory as relevant factors in viewing science. Moreover, discussions of affect, disposition, mindset and practice are of central concerns to understanding disciplinary practice and even the work of students (Engle & Conant, 2002; Jaber & Hammer, 2016; Wild & Pfannkuch, 1999).

These dimensions and guiding subdimensions reflect considerations I had in designing and assembling questions and tasks for my interviews of GTAs. My methodology, however, left room for solidified categories to emerge from the data in a similar fashion as Diamond and Stylianides’ (2017) work. I viewed the data with an open mind as I sought to categorize and identify themes in participants’ articulation of their views within each dimension.

Connections between disciplinary views and pedagogy. Following from the findings of researchers in mathematics education and science education (Russ, 2014; Schoenfeld, 1992; Speer, 2008; Thompson, 1984), I question how (or whether) my participants’ disciplinary views interact with and inform their pedagogical views. I make considerable effort in this work to map the influence of their disciplinary views in this process. However, I recognize the potential for other external influences on their views and teaching practice, like departmental regulations and suggestions from knowledgeable others. For example, the GTA coordinator might suggest that instructors include a cumulative exam worth 30% of students' grades; the GTA might then express that as part of their plan for teaching, even if it does not fully align with their disciplinary commitments for assessing students' statistical knowledge. It may even lead the GTA to reconsider their disciplinary commitments. By examining the interaction between GTAs' disciplinary views and articulated views for teaching, I hope to develop theory about how these spaces connect and the degree to which they ultimately inform instructional decisions.

Summary. This study is designed with the expectation that first-year statistics GTAs enter their graduate program with relatively diverse yet significant experiences that may influence their views of statistics. These disciplinary views may remain static across the study, being reinforced by their current experiences, or they may change on encountering experiences that challenge their views. I capture the emergence of these views across the study with the disciplinary framework outlined in this chapter. I also document the connection between their disciplinary views and their views for teaching introductory statistics, questioning how or whether these spaces interact. I also consider their teaching practices as solo instructors to assess whether their disciplinary views carry any significant influence when it comes time to make actual make instructional decisions. From my findings, I detail implications for statistics GTA training and professional development.

CHAPTER 2

REVIEW OF LITERATURE

In my review of literature, I begin by summarizing overarching themes pertinent to this work. In the first section, I synthesize ideas in the literature regarding the foundations of statistics, including how other experts have discussed the nature of statistics, the nature of doing statistics, and a statistical epistemology. These conversations provide a backdrop of highly-regarded perspectives from which to compare the developing disciplinary views of GTAs. I next consider best practices for teaching, specifically detailing pedagogical recommendations within statistics. Finally, I examine research on GTAs' content knowledge and experiences in statistics and other related STEM disciplines, followed by recommendations for the training and professional development of GTAs. The professional development literature sets up important considerations that I return to when I outline implications and future research in Chapter 7.

Disciplinary Foundations

The nature of statistics. Statistics historically found its roots in science as the logic of measurement (Stigler, 1986). It was the advent of the computer age in the 1960s that birthed a data revolution, and modern statistics developed as a discipline to pair inquiry and measurement with tools of quantitative analysis to allow for quantifiable comparisons (Tukey, 1962). More recently, statistics has found a unique disciplinary identity beyond measurement and mathematics; it is the process of exploring variability and measuring uncertainty (Cobb & Moore, 1997; Lindley, 2000). Rather than answering deterministic questions, Cobb and Moore argued that statistics is based in exploring possibilities with data-informed arguments.

As in many other disciplines like physics and economics, some knowledge of mathematics is necessary to do statistics, even though no knowledge of anything distinctly statistical is necessary to do mathematics (Cobb & Moore, 1997). Cobb and Moore draw the metaphor of poetry as a means of thinking about the interplay of mathematics and statistics: If statistics is poetry, then mathematics is the meter. Poetry is rather meaningless without the context of the words. Rhythm can be beautiful in and of itself, but meter on a neutral syllable would cease to be poetry without the complex arrangement of words to create meaning. Poetry exists to talk about the world and provide a canvas to abstraction, whereas meter exists as an entity independent of the context.

With the metaphor of poetry in mind, one may view statistics as dependent on mathematics, but drawing important identity in the meaning-making that happens. Moore (1998) went so far as to argue that statistics could just as well be considered a liberal art as it could be a hard science. De Veaux and Velleman (2008) reflected this sentiment: “Navigating through and making sense of [statistics] requires not just rules and axioms, but life experience and ‘common sense’” (p. 2). In drawing a contrast between statistics and calculus, De Veaux and Velleman noted that after solving for the rate of change in the water level of a cone, the calculus student does not need to investigate whether the container that water is pouring into is *really* a cone. As such, the larger process of statistics involves judgments to be made that depend not purely on objective measures, but ultimately on human decisions. In an interview with Woods (2016), Fred Benenson coined the term “mathwashing” to describe the public’s tendency to assume objectivity whenever a model or algorithm is involved. Using the Facebook “trending stories” algorithm as an example, he explained that such situations ultimately depend on someone to create, manage, and interpret the results—can objectivity ever be obtained from data?

In addition to subjectivity in design and contextual application, subjectivity may also be found amidst probabilistic calculations and models (Lindley, 2000). For example, Lindley explains that the practice of defining probabilities conditioned on certain assumed cases introduces subjectivity in terms of the nature of conditions being proposed or considered. Within a Bayesian approach to statistical analysis, Lindley explains: “The philosophical position is that your personal uncertainty is expressed through your probability of an uncertain quantity, given your state of knowledge, real or assumed. This is termed the subjective, or personal, attitude to probability” (Lindley, p. 302).

To truly distinguish statistics, it is also important to recognize something of the nature of mathematics. Naïve views of the two disciplines may simply note that statistics is more flexible or applied-based than mathematics (Diamond & Stylianides, 2017), but such descriptions discredit the true nature of mathematics (Skemp, 1976). Skemp explains that mathematics is often mistaken to be a system of procedures in which learners are pushed to develop what he terms *instrumental understanding*. Instead, Skemp believes mathematics should be viewed as a system of objects to be conceived and manipulated at the discretion of the user: a goal he terms *relational understanding*. When one considers that elements of our mathematical system are constructed, a relational understanding better reflects the work of mathematicians to begin with. For example, 2+2 does not necessarily equal 4, as the answer depends on what 2 (and 4) are being called to represent. If we employ a base 3 system rather than a base 10 system, 2+2 would equal 12. Furthermore, mathematics is a system that rests on assumptions (i.e., axioms); changing these axioms changes the nature of the system and the theorems that proceed, as can most readily be seen when the fifth axiom of a Euclidean geometric model is changed to allow for other systems of geometry (Greenberg, 1993).

While mathematical philosophers hold different views about whether mathematical theorems and formulas should be viewed as shadows of truths or mere sensible constructions

(Ernest, 1991), most mathematicians recognize that there is something inescapably social about the nature and development of mathematics (White, 1997). Mathematics serves to enlighten, to codify patterns, and provide a mathematical language to making sense of phenomena (Ernest, 1991). Statistics and mathematics naturally share much overlap, as statistics works with the language of mathematics and borrows similar ideas in its own pursuit (Cobb & Moore, 1997). Statistics would most clearly be distinguished in its attempts to model relationships amidst variability and its aims to make reasonable—but not necessarily perfect—explanations of phenomena from incomplete data (Cobb & Moore, 1997; De Veaux & Velleman, 2008).

The nature of doing statistics. Further insight on the unique nature of doing statistics is enlightened by recognizing what characterizes experts in the field. At a domain-general level, experts perceive information through conceptual frameworks or schemas to make sense of processes and ideas, in contrast to simply recalling disconnected facts (National Research Council [NRC], 2000). Because of this deep, conceptual knowledge, experts are well-positioned to answer ill-defined problems and propose flexible and creative solutions within their work (NRC, 2000). Furthermore, experts regularly engage in metacognitive activities as they acquire experience and use that experience to inform and inspire their work (Schoenfeld, 1992). Schoenfeld (1998) describes knowing mathematics well as knowing how to cook (in contrast to following recipes), an analogy that Garfield, Le, Zieffler, and Ben-Zvi (2015) take up in their descriptions of statistical experts. Experts also have a great deal of understanding about the context of the problem and can make sensible conclusions and implications from statistical results (Pfannkuch, 2011).

Along this line, *inferentialism* represents a core idea that undergirds statistical work (Bakker & Derry, 2011; Brandom, 2000). Put simply, this is the process of making claims or drawing conclusions about the population from a sample. These claims and conclusions are typically accompanied with varying levels of confidence, and require attention to sampling, variability, and even context. "Inferentialism attends to the distinctive nature of human awareness and puts inference at the heart of human knowing by providing an account of concept use that starts with reasoning rather than with representing" (Bakker & Derry, p. 6). Thus, understanding and engaging in statistical work involves awareness and strategic use of the inferential process.

Engaging in statistical work is also quite multi-faceted. In their seminal piece on the matter, Wild and Pfannkuch (1999) offer several different models that outline the mindset and practices involved in solving statistical problems. First, statistical work exists within an investigative process (Figure 2.1), in which statistical questions are being posed, studies are designed, data is collected, results are analyzed, and conclusions are generated and presented. Second, there are several types of thinking that the statistician will engage in. The statistician will model, visualize and change representations of data, consider variation, and integrate the statistical with the contextual. Third, the authors describe statisticians following an interrogative process (Figure 2.1); this cycle includes generating ideas and strategies, seeking information and inspiration, interpreting various considerations, criticizing information obtained, and then making judgments for next steps. Fourth, Wild and Pfannkuch define several dispositions that characterize those who engage in quality statistical work. This includes skepticism, imagination, curiosity, openness to new ideas, a propensity to seek deeper meaning, being logical, engagement, and perseverance.

From these discussions, themes emerge regarding the nature of statistics and the nature of doing statistics. First, statistics involves a close connection to mathematics. It also involves a

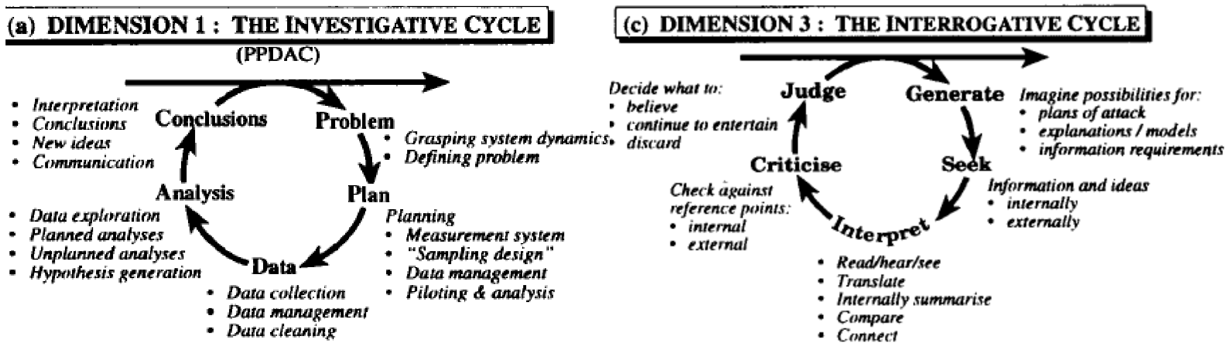

Figure 2.1. The Investigative and Interrogative Processes (Wild & Pfannkuch, 1999)

pursuit toward answering questions—sometimes ill-defined—that do not have deterministic answers. On that point, statistics is quite scientific in nature by making measured claims with the caveat that no statistical claim is certain. Regarding the nature of solving statistical problems, statistics involves proper attention to the probabilistic/mathematical underpinning (the meter of the poem, if you will) and the guiding principle of inferentialism. Statistical problem-solving also involves a deep understanding of the context and an inquisitive pursuit toward making meaning. Good statistical work may also be creative—even artistic—in its efforts to construct reasonable claims and models from data. Additionally, those working on statistical problems should be skeptical, curious, and perseverant as they seek insight to their questions.

Epistemological considerations in statistics. In addition to considerations in the literature regarding the nature of the discipline and disciplinary work, I also bring in perspectives on the nature of knowledge and knowledge development in statistics. Building upon the epistemological dimensions identified by Hofer and Pintrich (1997), Diamond and Stylianides (2017) completed an exploratory study that targeted the disciplinary views of statisticians in academia. The authors offered their findings as examples of expert statistical epistemologies, providing detailed descriptions of the respondents' reflections on each of the dimensions. To properly acknowledge a domain-specific aspect of the participants' disciplinary views, the authors synthesized participants' responses within each dimension into categories of response (Table 2.1). Participants each contributed responses or examples within each dimension that spanned several of the categories. Thus, the categories do not fully describe people, but rather characteristics of the discipline of statistics that participants identified.

Table 2.1. *Proposed Categories of Response within a Statistical Epistemology*

Dimensions	Categories of Response
The certainty/simplicity of knowledge	Objective Constructed Socio-culturally dependent
The attainability of truth	Constructed Discovered Irrelevant
The justification for knowing	Data Problem-driven research Pure intellectual pursuit Sociocultural motivations
The source of knowledge	Developed through process of criticism and refinement Collaborative Nature

Regarding the "certainty of knowledge," Diamond and Stylianides (2017) noted that participants described some aspects of statistics that were objective (e.g., logic, probability, proof), some as constructed (e.g., Bayesian statistics, need for openness, model choice), and some as socio-culturally dependent (e.g., media and public reporting, historical context, shift of statistical paradigms towards Bayesian models). Their views about the "attainability of truth" generally recognized an inherent construction in statistics being based on assumptions and axioms, with certain axiomatic consequences and solutions being discovered through these constructed means. Some respondents mentioned that ontological positions were unnecessary to parse out in statistics, and that engagement in statistics had no stake in such an answer.

Four categories regarding the “justifications for knowing” emerged in the interviews, with all participants offering data as the central motivation for the discipline. The participants, however, contributed various additional ideas, including real world problems (e.g., need for statistical research), intellectual pursuit (e.g., the joy of learning/applying), and sociocultural context (e.g., increasing consumption of goods in a consumerist society, management of the finance sector). Finally, all participants articulated a constructivist perspective on the source of statistical knowledge, meaning that statistical knowledge is not waiting to be discovered, but instead is negotiated and imperfectly developed to give meaning. This perspective highlights statistics as propagated through conferences and journals, with research being read, critiqued, synthesized, and built on over time to contribute to statistical knowledge. Paralleling this process is the collaborative nature of statistics. One professor stated that “the idea of someone sitting on their own doing statistics is just laughable” (Diamond & Stylianides, 2017, p. 347), highlighting that statistics is based in the context of other people’s work and made meaningful through collaboration.

An important takeaway from Diamond and Stylianides’ (2017) findings is the variety of perspectives elicited on this matter. Previous work on epistemology has often defaulted toward stage-based theories—with novice conceptions viewing knowledge as discrete, absolute, and transferred, while expert conceptions view knowledge as more nuanced, relative, and constructed (King & Kitchener, 1994; Perry, 1970). Others have questioned stage-based theories and proposed models that view individuals as holding views on multiple continuums (Schommer, 1990). More balanced positions have emerged that see merit to both perspectives, with agreement among researchers and psychologists that certain disciplinary views are more sophisticated and consistent among experts, but rejection of the claim that such progressions are strictly linear and non-variable (Richardson, 2013).

In harmony with the above findings, I work to avoid blanket labeling of each GTA in my study as fully representing a particular view. Rather, I regard each one as a complex individual holding nuanced and contextual views. In Chapter 4, I attempt to pair each GTA's epistemic views with their articulated perspectives of the discipline by sharing models that represent their views. In Chapter 5, I unpack the relevant experiences that inspire their disciplinary views to add clarity to their perspectives.

Pedagogical Foundations

In the previous section, I outlined important disciplinary considerations and perspectives reflected by statisticians and statistics educators. From these disciplinary foundations, I now examine pedagogical foundations relevant to curriculum and instruction in statistics. I begin by discussing the various aims of statistics education, and specifically the aims of introductory courses. Second, I document the recommendations of the statistics education community for what should be taught in an introductory course.

Aims of statistics education. Before addressing specific aims for introductory statistics, it is important to first consider the varying roles people may take with regard to statistics. Lindley (2000) makes a distinction between two different roles in the discipline of statistics: the statistician and the client. The statistician is to be well-versed in statistical methods and probability theory (including Calculus and other mathematical domains), assisting clients as needed. The client's role is to identify statistical questions in a specific discipline and properly apply statistical findings for that specific context. Two perspectives emerge: one of statistics as a discipline in and of itself and another that sees statistics as a tool applied *to* a discipline.

Where Lindley (2000) used the word client, others have suggested similar notions with titles such as "statistical citizen" or "statistically literate citizen," meaning someone without knowledge and expertise to conduct a statistical investigation, but with enough knowledge to recognize when statistical analysis is appropriate and understand the implications that statistical results have within their lives or field of expertise (Rumsey, 2002). The statistically literate citizen is loosely related to the client role in needing to have a more knowledgeable other assist in analysis, but this individual has developed critical thinking skills to judge and make sense of statistical findings in personally relevant situations.

With the paradigm shift of "big data," a new field has emerged: data science. Organizations like the American Statistical Association (ASA) are beginning to recognize this distinction as noteworthy, describing data science as a field that pairs statistics with sophisticated computing techniques (ASA, 2015). With this change to the field comes the need for an alternative to the traditional statistician: data scientists and analysts. These individuals need knowledge to complete statistical investigations using computer tools, but they may not necessarily need deep understanding of probability theory and mathematical statistics (e.g., sufficient statistics, measure theory, etc.). Statisticians may be better positioned to create new techniques supported by mathematical underpinnings, while data scientists may be more well-versed in flexible computing techniques and exploratory analytic skills.

The next logical step is to consider the aims of introductory courses and subsequent courses in light of these potential roles related to statistics. Much has been written on what the undergraduate statistics curriculum—and introductory courses in particular—should emphasize (e.g., ASA, 2005, 2016; Cobb, 1992; Pearl et al., 2012). While a list of methods and procedural skills may still be taught in these courses, statistics educators maintain that certain cognitive goals are invaluable in preparing any student to participate and interact with statistics (Pearl et al., 2012). Three constructs highlighting different general aims for these courses have emerged from the literature that form the basis of these recommendations—statistical literacy, thinking, and reasoning (Chance, 2002; delMas, 2002; Garfield, 2002; Rumsey, 2002). These constructs are not mutually exclusive; rather all three aims overlap considerably with one another. These three constructs also map nicely to the three roles outlined previously.

Statistical literacy. Statistical literacy is often considered the foundational skillset statistics educators want to promote in any high school or college statistics curriculum (Rumsey, 2002). In our modern-day age of information, we need to prepare a generation of statistically literate citizens who can be critical and informed consumers of data. Garfield (1999) stated that statistical literacy involves the understanding of statistical terms and symbols that citizens will see in the news (e.g., margin of error) and the ability to meaningfully interpret graphs and tables. Gal (2000) added that promoting statistical literacy also demands we equip our students with skills to critically evaluate data-based arguments and form meaningful opinions related to such information.

Gal (2000) and Rumsey (2002) posited that statistical literacy ideally goes beyond term recognition and critical thinking skills to consume everyday information—it is also an overarching knowledge of the process of research. Specifically, statistical literacy is an awareness and basic understanding of the investigative cycle (Wild & Pfannkuch, 1999; ASA, 2016), as presented previously in this chapter (Figure 2.1). Statistically literate citizens recognize the potential for statistics to answer or explain questions involving variation. These skills are beneficial for the ordinary citizen to appreciate research as an integral part of any discipline and to recognize situations in which statistical analysis could be conducted and carried out to make informed decisions.

Statistically literate students should understand how to comprehend the basic structure of a statistical study and critically evaluate the validity of the claims made, even if they never complete a statistical study themselves. Understanding might be demonstrated in attending to details about a study, such as recognizing the study's design, the sample size, and limitations in the findings (Gal, 2000). This knowledge also opens the possibility for communication with colleagues or community representatives to support calls for action based on statistical findings. I summarize statistical literacy as the ability to critically evaluate data-based claims, a basic understanding of the research process, the ability to assess a study's strengths and weaknesses at a fundamental level, and to apply statistical findings in one's area of expertise.

Statistical thinking. While statistical literacy involves an individual's capacity to be a critical consumer of data-based reports, statistical thinking involves an individual's capacity to be a producer of data-based reports (Chance, 2002). While the statistically literate citizen may recognize variability in normal life or identify situations where statistical analysis could be beneficial, statistical thinkers are more attuned to this everyday variability and readily look for patterns and models to explain this variation (Snee, 1990). Statistical thinkers possess more than a skillset; rather they flexibly engage in the practices of good design, exploratory data analysis, identification of key relationships, and modeling of patterns (Chance, 2002). Wild and Pfannkuch (1999) captured these characteristics by conceptualizing disciplinary engagement in statistics in terms of types of thinking, a questioning mindset, and dispositions (Figure 2.1). Each of these dimensions constitutes a cycle or a list of practices, and someone truly *doing* statistics will be engaged in one particular phase or practice from each of the four dimensions.

Chance (2002) discussed components of statistical thinking as “habits,” and central to these habits is a deep connection between the statistics and the context. Chance shared several characterizations of statistical thinkers. For example, statistical thinkers design their study carefully, understanding what kind of analysis would best address the particular context studied; they will understand the details involved in collecting or measuring data and make choices that are ultimately rooted in what is meaningful for the given context; they can determine what steps should be completed next without having to be instructed what they should do; and they question the validity of a study and propose alternative methods for answering those questions. Additionally, advanced statistical thinkers can modify or perhaps even derive methods to statistically investigate problems without needing to follow a set of prescribed methods in a textbook.

Statistical reasoning. As defined by Garfield (2002), statistical reasoners possess many of the same skills and habits of statistical thinkers. However, the primary differentiation is in statistical reasoners’ understanding of statistical processes. For example, the statistical reasoner has a deep conceptualization of sampling variation, why characteristics of a sample can help us infer conclusions about the population, and why (and which) measures of center and spread can help us understand and compare groups. An example of this differentiation might best be found in how statistical reasoners conceptualize sampling distributions and the Central Limit Theorem.

In their framework to assess students’ abilities to reason statistically about sampling variability, Chance, delMas, and Garfield’s (2004) described students at the highest level as explaining the process of the Central Limit Theorem and demonstrating sufficient understanding of *why* that process works in terms of sampling variability and central tendency. Garfield (2002) provided a generic template of this framework that can be applied to any statistical topic:

> The student has a complete understanding of a statistical process, coordinates the rules and behavior [sic]. The student can explain the process in his or her own words with confidence. For example, a student can explain what a 95% confidence interval means in terms of the process of repeatedly sampling from a population (Garfield, 2002, para. 46).

In contrast to statistical thinking, which is fostered through statistical investigations and instructor feedback, statistical reasoning is best developed through computer simulations, activities with manipulatives, class-wide discussions, and writing prompts to reflect about the meaning of various statistical concepts (delMas, Garfield, & Chance, 1998).

Summarizing the aims of literacy, thinking, and reasoning. In reflecting on the three general roles in statistics described previously (e.g., the statistically literate citizen, the data scientist, the traditional statistician), I view the three aims of statistical literacy, thinking, and reasoning as describing the primary learning goals for each of these roles respectively. All three participate together in the art of statistics in different ways, but all possess overlapping knowledge, understanding, and experience as well. These aims serve to highlight the needs of different individuals moving through introductory courses, potentially with different introductory courses emphasizing different aims.

Recommendations for teaching statistics. One of the earliest efforts to present a list of formal recommendations for teaching statistics came from the "statistics focus group," documented and presented by George Cobb (1992). These recommendations highlighted concerns of statistics courses being removed from the context of data and focusing instead on mathematical underpinnings and probability theory. Cobb and Moore (1997) furthered these ideas by categorizing the "content of statistics" into three general phases: (a) data production, (b) data analysis: exploration and description, and (c) formal inference: the argument against chance.

The authors argue for balancing the mathematics of formal inferential methods with contextually-focused exploratory data analysis. By teaching exploratory data analysis first, design would act as the bridge between data analysis and formal inference. They also called for a downplayed role for formal probability in an introductory course, citing that inferential reasoning can be developed without forming a basis in probability rules.

The ideas discussed by Cobb (1992) and Cobb and Moore (1997) have been further developed through the construct of Informal Inferential Reasoning (Gil & Ben-Zvi, 2011; Rossman, 2008). Informal inferential reasoning stresses attention to context rather than procedures and allows students to make sense of the situation using their own experiences and ideas. In this way, informal inferential reasoning resonates with constructivist principles by providing opportunities for student-centered knowledge construction rather than emphasizing a transfer model of knowledge and learning (NRC, 2000; Hammer, Elby, Scherr, & Redish, 2005). Additionally, statistics educators have offered instructional visions that immerse students in statistical argumentation, both in terms of explaining concepts as well as making analytical decisions (Cobb & McClain, 2004; Garfield & Ben-Zvi, 2009). These instructional visions move beyond using correct procedures and completing computation and instead emphasize decision-making and consideration of reasonable measures to address a contextual question.

Garfield and Ben-Zvi (2009) presented a model for a statistical reasoning learning environment, described as an "interactive combination of text materials, class activities and culture, discussion, technology, teaching approach and assessment" (p. 73). One way Garfield and Ben-Zvi's instructional vision has been taken up is through the use of computer simulations (Chance et al., 2004; Chance & Rossman, 2006; Watson & Wright, 2008). For example, Chance and colleagues documented extensive work their research team has done to find how effective simulations have proven to be in helping students making sense of sampling distributions and the Central Limit Theorem. Likewise, Tinkerplots has been documented to assist students to reason informally about inference while being granted autonomy to interact with the virtual environment (Watson & Wright, 2008). Fluency with high-tech tools is another critical skillset for those who work in statistics, and it represents an important disciplinary gateway into data science (ASA, 2016). With much statistical work being completed with the assistance of software, many have taken up the challenge to teach data science skills (including basic programming) in a first and second course in statistics (Hicks & Irizarry, 2018)

As described earlier, inquiry and the investigative process are at the heart of statistical thinking (Wild & Pfannkuch, 1999), which includes the difficult responsibility of posing rich, statistically-based problems to students, facilitating discussions about robust research designs and data collection methods, teaching exploratory data analysis and proper selection of statistical analysis, and guiding students to proper conclusions based on the design and the statistical findings (e.g., Allmond & Makar, 2010; Cobb, 1999; Makar & Fielding-Wells, 2011). While the depth and complexity of such tasks would depend on the previous experiences and needs of the students, the authors cited above see such experiences as critical for students in introductory courses, and potentially as early as middle-grades education.

The GAISE college report (ASA, 2005, 2016) currently serves as the community-regarded standard for what an introductory course should accomplish. Borrowing many of the themes and ideas documented above into their recommendations, GAISE offers six general guidelines for statistics teaching at the college level:

- Teach statistical thinking.[1]
- Focus on conceptual understanding.
- Integrate real data with a context and purpose.
- Foster active learning.
- Use technology to explore concepts and analyze data.
- Use assessments to improve and evaluate student learning.

The GAISE Report unpacks how the introductory course is balancing a number of competing priorities:

> Certainly, an introductory course will involve some computation, though most should be facilitated by technology. It is desirable for students to be able to make decisions about the most appropriate ways to visualize, explore, and, ultimately, analyze a set of data. It will not be helpful for students to know about the tools and procedures that can be used to analyze data if students don't first understand the underlying concepts.

The GAISE Report also provides a vision for *conceptual understanding* (mirroring Skemp's [1976] "relational understanding") by suggesting a course formed around big ideas (e.g., random sampling, distribution, sampling variation, inferentialism) rather than emphasizing mastery of techniques without deeper understanding. Additional goals and recommendations in the document highlight the need for students to understand both the conceptual underpinnings of statistics as well as the mindset needed to engage in statistical work (Wild & Pfannkuch, 1999).

The guidelines and objectives posed by GAISE reflect broad considerations for what should be included in an introductory course. However, the report also explains that there is no

[1] ASA (2016) contains sub-points under "Teach statistical thinking" that include the following: (a) Teach statistics as an investigate process of problem-solving and decision-making, and (b) Give students experience with multi-variable thinking.

universal structure or purpose for introductory courses, and particular course goals should reflect the needs of the students in each course (ASA, 2016). The statistical experiences that students in Biology need may be different than those in Business, and certainly different from those of students in non-quantitative disciplines. In the latter case, a course focusing on statistical literacy may be more appropriate (Engel, 2017). Likewise, prospective mathematics and statistics majors may benefit from an introductory course with heightened emphasis on statistical reasoning.

Statistics GTAs: An Opportunity in Need of Attention

I have presented disciplinary perspectives on statistics, discussed potential aims for introductory statistics courses, and reviewed recommendations for the teaching of college statistics. I now turn to reviewing literature relevant to the training and professional development of statistics GTAs. With GTAs taking a growing role in undergraduate statistics instruction (Blair, Kirkman, & Maxwell, 2013), much work remains to be done to improve instructional training (Pearl et al., 2012). My review addresses the content knowledge, disciplinary perspectives, and unique experiences of GTAs. I also delve into research on effective training practices and professional development structures for GTAs. Limited research exists on statistics GTAs; therefore, I supplement my review with research on GTAs in mathematics and science, as well as relevant research on teachers of statistics in Grades 6-12.

Content knowledge and disciplinary views of statistics GTAs. While my research is not directly concerned with assessing GTAs' content knowledge, reviewing this literature still provides a helpful consideration for understanding statistics GTAs' disciplinary perspectives and curricular views. Little published research exists that directly assesses GTAs' subject matter knowledge of statistics, but Noll (2011) provides a critical glimpse into statistics GTAs' knowledge about empirical distributions and sampling variation. By surveying 68 statistics

GTAs and conducting think-aloud interviews with five others, Noll found these GTAs to demonstrate mastery of procedures and theoretical properties. However, she discovered GTAs in her survey and interview data to consistently struggle with more conceptual components of the task. An example of one task GTAs completed is shown in Figure 2.2.

A jar contains 1000 candies, 750 are red and 250 are yellow. The candies are mixed well. Suppose that you pull a random sample of 10 candies from the jar, record the number of reds, put the candies back in the jar and mix them up. Suppose you do this 50 times. How many times out of 50 do you think you would get a handful of 10 candies with:

Number of Red Candies in Handfuls of 10	Prediction
0 red	
1 red	
2 red	
3 red	
4 red	
5 red	
6 red	
7 red	
8 red	
9 red	
10 red	
Total	50

Figure 2.2. The Prediction Task (Noll, 2011)

In her findings, Noll noted that her participants struggled with many of the same concepts that Grade 6-12 students and teachers find difficult (Reading & Shaughnessy, 2004). For example, many GTAs failed to appropriately balance sample representativeness and sample variability, a common error among high school students. While a majority of the GTAs expressed sophisticated common content knowledge in applying theoretical distributional models (i.e., binomial or hypergeometric) to make predictions, interview results suggested that GTAs lacked specialized content knowledge to develop conceptual links between these models and the actual tasks. For example, one GTA was conflicted as she considered likelihoods by imagining the bowl and drawing candies; she had difficulty reconciling the distributional predictions with her “gut” predictions. Noll summarizes her findings:

> Despite their strong statistical knowledge of formal probability distributions, many of the GTA survey participants, as well as the interviewees, did not appear to apply their statistical knowledge when making predictions using empirical sampling distributions. The research presented in this paper suggests that these GTAs may have compartmentalized their theoretical knowledge of statistics, creating difficulty in applying that knowledge when working with empirical data (p. 69).

These findings suggest a critical gap between GTAs’ theoretical and mathematical understanding of statistics and the more contextually-based approaches necessary to make sense of empirical results.

Dolor (2017) followed Noll’s (2011) research by studying GTAs’ knowledge of probability in the context of hypothesis testing. He noted that most GTAs could correctly answer questions addressing more procedural knowledge, but some struggled to conceive of p-values conceptually. For example, pairing a p-value with the symbolism for conditional probability (e.g., the probability given the null hypothesis is true) was novel and/or conceptually challenging for some GTAs. In describing their development of a statistics GTA training program, Green and Blankenship (2014) echo the findings of Noll and Dolor: “We are still finding gaps in TAs’ understanding of variability, sampling distributions and how these concepts connect to statistical inference” (p. 2). Despite limited research, there seems to be a consensus that GTAs lack robust *conceptual* knowledge around the big ideas undergirding an introductory course.

In addition to their content knowledge, teachers and instructors may also hold disciplinary views that influence their pedagogical views and teaching practices (Abd-El-

Khalick, Bell, & Lederman, 1998; Speer, 2008; Thompson, 1984). There is limited research addressing this connection among college instructors, but Thompson's work with middle-school mathematics teachers provides a glimpse of how one's philosophy for mathematics can shape one's mathematical teaching practices. Thompson explained that Jeanne's views about mathematics being "accurate, precise, and logical" (p. 110) naturally informed her views that her role as the teacher was to present the mathematics in a clear, straightforward manner without digressions or changes in plan. For example, a student asked how something could be less than 1%, as they are in the stock market; Jeanne, however, dismissed this discussion, noting that it was outside the scope of their learning goals.

At the undergraduate level, Hammrich's (2001) study with Biology GTAs found that teaching instruction focused on developing conceptions of science as constructed seemed to be an important scaffold in the GTAs' pedagogical growth. With this disciplinary perspective, the GTAs were more likely to value student construction of concepts, rather than merely memorizing and recalling definitions and terms. In mathematics, Speer (2008) documented the case of a GTA (Zachary) who already expressed expert disciplinary notions. He described mathematics as beautiful and somewhat flexible, but he struggled to connect these views to the context of the course he taught. Zachary described the content of his course as a foundational set of procedures and techniques and was not sure how to integrate the beauty of mathematics into the content he believed he needed to teach.

In his study of four high school statistics teachers, Eichler (2008) proposed a spectrum of ideological positions, with "traditionalists" on one end and "everyday-life preparers" on the other. Under Eichler's framing, a traditionalist privileges mathematical underpinnings and theoretical models as the core of statistics (i.e., statistical reasoning), while an everyday-life preparer emphasizes the context and applied methods above mathematical content (i.e., statistical thinking and literacy). Outside of Eichler's work, there appears to be little work seeking to connect the disciplinary views of statistics teachers and instructors to pedagogical views.

Pedagogical views of mathematics and statistics GTAs. Studies have identified critical connections between GTAs' views about teaching and learning and their actual teaching practices (Kember & Kwan, 2000; Sandi-Urena & Gatlin, 2013). In statistics, Justice, Zieffler, and Garfield (2017) developed the Graduate Student Statistics Teaching Inventory (GSSTI) to assess GTAs' professional development experiences, pedagogical views, and teaching practices. In their survey of 213 solo and recitation GTAs across 38 institutions, the research team found many encouraging results among GTAs' professed pedagogical views: an overwhelming majority of GTAs valued the use of open-ended problems in assessment, and a considerable number valued providing students formative feedback. However, pedagogical views and teaching practices were not always aligned. They reported that 90% of the GTAs who stated lecture should *not* be the primary instructional method used still reported using lecture in that capacity; likewise, computer simulations and software were not reportedly utilized to the degree that it was valued. The frequent use of activities in class was aligned with GTA views about active learning, but the *nature* of the activities GTAs used was not assessed in the survey. These findings align with general findings in the literature that reform-oriented teaching beliefs are not sufficient to ensure reform-oriented teaching practices (Ball & Cohen, 1999; Thompson, 1992). There is work to be done to understand how to bridge the gap between self-reported pedagogical views and the actual instructional practices being carried out by GTAs in the statistics classroom.

The survey administered by Justice et al. (2017) reported that only 35% of statistics GTAs surveyed reported learning about professionally-endorsed guidelines for the teaching and learning of statistics (e.g., GAISE) as part of their training—a somewhat concerning statistic. Findings from DeFranco and McGivney-Burrelle (2001) reflect a similar dearth of deep pedagogical understanding for GTAs in mathematics. The authors reported that GTAs in one mathematics department struggled to describe *how* students learn and instead named more superficial practices (e.g., students learn by reading the textbook, reviewing their notes, or memorizing information). These findings align with Gardner and Jones' (2011) review of research on GTA training experiences in science departments.

Thompson (1992) proposes a model to describe teachers holding varying pedagogical beliefs and desires; however, these beliefs may exist more centrally or peripherally in terms of importance. Thompson explains that at points of tension, teachers' practice will reflect the beliefs they hold most centrally. The mathematics GTAs in DeFranco and McGivney-Burrelle's study (2001) reportedly adopted somewhat constructivist views at a peripheral level about the teaching and learning of mathematics, but these GTAs still seemed to hold central views about the role of the instructor as an authority figure who transmitted knowledge. These research findings suggest that changing instructor views is a long-term professional development goal that requires teaching experience, pedagogical dissatisfaction, and opportunities to reflect (DeFranco & McGivney-Burrelle, 2001; Justice et al., 2017; Loucks-Horsley, Stiles, Mundry, Love, & Hewson, 2010).

Through her focus-group work with first-year statistics GTAs, Green (2010) reported that many GTAs were aware of their own lack of knowledge about introductory statistics curriculum and statistics teaching strategies. Several students expressed difficulty in picking out key ideas from the textbook around which to build their lessons. GTAs felt they could comprehend and follow the textbook, but they found translating that content into a lesson to be challenging. Green corroborates Noll's (2011) and Dolor's (2017) findings in suggesting that statistics GTAs often demonstrate advanced content knowledge of statistics, but find it challenging to think about problems from the perspective of an introductory student.

Pierce and Chick (2011) closed their chapter on statistics teachers' pedagogical views with a collection of topics needing further research. These topics include ideas such as (a) exploring teachers' views about the relationship between mathematics and statistics, (b) examining teachers' views about the components of statistical thinking they should develop in their students, (c) identifying barriers teachers face in developing their students' statistical thinking, (d) assessing how teachers' situation and background affect their views about teaching statistics, (e) identifying interactions among views, technology use, and statistics learning, and (f) exploring the influence of teachers' views on their classroom practice. This dissertation explores many of these topics, focusing specifically on GTAs.

Key experiences and influences on GTAs. In charting statistics GTAs' early experiences with teaching, Green (2010) noted that many GTAs expressed anxiety over their roles and often felt that clear and focused direction regarding their responsibilities was not provided. Much of this anxiety stemmed from concerns about general pedagogical issues, like preparing the right amount of material to cover one period, dealing with classroom management issues, and balancing friendliness with strictness, among many other things.

Additionally, research finds that mathematics and science GTAs often emulate the transmission-style instruction they have experienced as mathematics students, often lacking vision for a more active, reform-oriented learning environment (DeFranco & McGivney-Burrelle, 2001; Hammrich, 2001; Kung, & Speer, 2009). As a result, seeing and experiencing instruction that models content-rich, student-centered practices—whether as a student or as a participant in a GTA training program—is key to motivating reform-oriented teaching practices (Kung & Speer, 2009).

International GTAs, who comprise a large proportion of the statistics GTA ranks (NSF, 2002; Moore, 2005), often have unique experiences that merit special consideration. Heidish (2006) reports that international GTAs who are non-native English speakers may experience challenges and anxiety regarding speaking and listening comprehension. International GTAs may also have limited exposure to U.S. classroom norms, thus potentially having different expectations of undergraduate students' mathematical abilities or of typical classroom management styles (Chae, Lim & Fisher, 2009; Tang & Sandell, 2000). Kim (2014) found international GTAs in one mathematics department tended to favor content-focused lectures, while U.S. GTAs spent substantially more time completing example problems on the board. For many international GTAs, Kim connected these differences in international GTAs' teaching practices to tendencies by some to avoid direct interactions and discussions with students, or previous professors' emphasis on derivation of theorems and methods.

It is also important to consider how international GTAs find community in their departments, and whether they are being understood and included by community members. A case study on GTA community in a department of mathematics found some faculty members misinterpreting the social norms of their Chinese GTAs (Jenkins, 2000). As one example, Jenkins reported that Chinese students may insert pauses in discussions out of politeness or respect when discussing matters unfamiliar, but some faculty members interpreted such silent pauses as social cues of avoidance or tentativeness around responsibilities. Fear about losing assistantships by admitting weaknesses to faculty members was also a factor discussed by Jenkins. Chinese GTAs in her study were also more likely to discuss issues with their Chinese peers rather than American peers, citing their shared language as well as shared experiences and mutual support as reasons for these deeper connections. From the perspective of a community of practice, the cultural identity of GTAs is a factor to consider in GTA training and professional development. Even if GTA training programs offer robust opportunities for growth, divides in the community could inhibit some from taking advantage of those opportunities to the fullest.

While numerous qualitative studies have identified critical issues unique to international GTAs, broad assertions about international GTAs should still be made cautiously. In a survey of 202 GTAs from China, Korea, India, Sri Lanka, Turkey, and the United States, Gorsuch (2012) did find that pedagogical views and attitudes were significantly different across nationalities. However, even within nationalities, other factors (e.g., home country teaching experiences, U.S. teaching experiences, U.S. student experiences) were also significant predictors for certain responses, signaling that GTAs of the same nationality still reflect a diverse set of experiences and views related to teaching. With Gorsuch's findings in mind, I summarize the previous research findings by stating that international GTAs *may* experience some of these unique challenges to varying degrees.

Effective professional development for GTAs. I move now to consider research and recommendations on the professional development (PD) of statistics GTAs. While my dissertation is not directly concerned with analyzing the nature of the training and professional development opportunities that my participants experience, I do make conclusions relevant to this body of work (featured primarily in Chapter 7). In this section, I begin with a review of literature on research-based best practices in PD. Then I will discuss PD recommendations more specific for GTAs, followed by discussions specific to statistics GTA training and PD.

Research-based practices and recommendations for PD. PD for teachers and instructors is a vital yet incredibly difficult and complex area of study (Hawley & Valli, 1999). "A widely held belief is that teachers' practices change as a product of changes in curriculum, standards, and assessments" (Ball & Cohen, 1999, p. 4). Unfortunately, reforming teacher practice is not as simple as distributing a research-based curriculum or holding seminars that tell teachers how to teach. To create a transformative learning environment for teachers aligned with constructivist perspectives on learning, PD should first create cognitive dissonance, followed by time and ongoing support for reflection and change, and finally enable the development of a new repertoire of practice that fits what teachers have learned (Thompson & Zeuli, 1999).

In her synthesis of research-based recommendations for PD among teachers, Desimone (2009) identified five characteristics of PD that have been linked to successful changes in teacher knowledge or practice: (a) a focus on content, (b) a foundation in active learning, (c) a coherence with teachers' program structure, (d) an adequate duration for reflection and change, and (e) collective participation (e.g., Garet, Porter, Desimone, Birman, & Yoon, 2001; Hill & Ball, 2004; Lieberman & Miller, 2008; Loucks-Horsley et al., 2010; Penuel, Fishman, Yamaguchi, & Gallagher, 2007). Hill and Ball lobby for a content-focused PD in mathematics based on teachers' need to develop specialized content knowledge. In their survey of mathematics and science teacher PD programs across the country, Garet et al. found an association between teacher-reported learning gains and the structure of the PD in regard to active learning opportunities. Penuel et al. built on the work of Garet et al. with another survey, finding that teacher learning was strongest among those who found the PD to be coherent with the curriculum and program structure they worked in. Garet et al. and Penuel et al. also found positive links between teacher learning and the duration of the program; PD should be of adequate duration to provide opportunity for teachers to reflect and cognitively advance their own understanding (Loucks-Horsley et al., 2010). Lieberman and Miller (2008) makes the case that PDs should bring together teachers with common goals who will continue to work together as a community to support one another toward change.

To fulfill the practices outlined by Desimone (2009), many researchers have emphasized the importance of embedding PD in the context of the classroom by looking at student work, watching and reflecting on classroom video, and engaging in tasks similar to those that would be completed by their students (Ball & Cohen, 1999; Borko & Koellner, 2008; Suzuka, Sleep, Ball, Bass, Lewis, & Thames, 2009; van Es & Sherin, 2002). Such tasks help teachers dig into conceptual ideas, unpack student thinking, and ponder teacher responses to facilitate cognitive learning gains as they become more attuned to how students in their classrooms construct their knowledge (van Es & Sherin, 2002).

Long-term PD should involve opportunities for feedback and growth through teaching observations (Fishman, Davis, & Chan, 2015). Teachers can benefit from meeting with colleagues and advisors who have observed their work, and they can also develop a more complete instructional vision by observing other teachers. Teachers should also feel they are part of a community of practice, supporting one another's professional growth and sharing joint enterprise in improving their teaching (Lave & Wenger, 1991; Little, 2003; Putnam & Borko, 2000). Furthermore, such communities of practice should focus on conceptualizing problems of practice rather than focusing predominately on pacing and logistics (Horn & Little, 2010).

Effective PD for GTAs. Many of the research-based practices for PD identified previously are reflected in research among GTAs and undergraduate instructors. In their review of literature on the dissemination of curriculum and pedagogy, Henderson, Beach, and

Finkelstein (2011) remarked that developing and distributing “best practice” materials to STEM faculty members is ineffective at changing teaching practices. Henderson and colleagues note that successful changes were accompanied by focused efforts over an extended period of time, opportunities for feedback, and a focus on changing faculty views and conceptions. Conclusions from their review align with arguments made by Loucks-Horsley and colleagues (2010).

To contextualize the review from Henderson et al. (2011), I discuss findings from Pentecost, Langdon, Asirvathum, Robus, and Parson (2012) in their work to support student-centered teaching practices among GTAs in Chemistry recitations. The researchers created a 3-day content-intensive, active learning workshop for GTAs, allowing them to engage in the content in conceptually-robust ways and see instruction modeled in a student-centered format. The researchers used GTA feedback from the first year to inform and improve the course during the second year, replacing a session on learning theory with an opportunity for GTAs to facilitate an actual recitation activity in small groups. Pentecost and colleagues reported that the new cohort of GTAs drastically increased GTA-to-student dialogue in their recitations. They also found student evaluations showed significant improvement with the cohort that participated in practice recitations. In summary, opportunities to engage with students and make sense of student thinking played a key role in improving the frequency and depth of classroom conversations.

Researchers have also reported on the potential benefits of mentoring to reduce anxiety and offer feedback to new GTAs learning the ropes (Ellis, 2014; Gardner & Jones, 2011; Williams, 1991). However, as noted by Ellis, mentoring can look very different across institutions. Mentoring may be a component of a larger apprenticeship model in which GTAs develop close professional relationships with professors (e.g., Alvine, Judson, Schein, &

Yoshida, 2007). Mentoring may also be rather informal, with experienced GTAs possibly filling these roles and/or no specific guidelines provided to mentors (Ellis, 2014). Mentoring may even be detrimental by perpetuating a stale, non-innovative approach to teaching (Putnam & Borko, 2000). Additionally, faculty mentors may create too large a power differential, potentially imposing their teaching philosophies rather than seeking to develop those of the GTA (Korpan, 2014). Overall, the limited research on GTA mentoring provides mixed conclusions.

Findings from White and Nonnamaker (2008) suggest that setting up regular interactions among GTAs and creating joint enterprise through shared goals will foster a meaningful community of practice among GTAs and instructors. Pentecost et al. (2012) found that the GTAs in their study noted the community they formed was one of the most valuable aspects of their preparation course. However, GTA communities can be fractured when GTAs feel that it is a community they *must* be a part of rather than one they *choose* to be a part of (Ellis, 2014). In Ellis' study of mathematics departments across four institutions, she noted that GTAs in two of those institutions seemed to find their identity in the research community of mathematicians, viewing their assistantship as responsibilities to manage rather than identity-shaping experiences. These GTAs typically relied on lectures and teacher-centered problem sessions in classes, lacking camaraderie around discussing innovative teaching methods or delving into student thinking. In her survey of statistics GTAs' pedagogical views and their experiences in a community of practice, Justice (2017) notes that most GTAs report having been required to attend GTA meetings to discuss teaching matters; however, their attendance at these meetings were required for only a year or less. While many GTAs did report finding fellow GTAs most available and easiest to talk to, it was faculty members who provided the most *influence* on their own pedagogical views.

Some researchers have also reported on the value of autonomy and ownership in GTAs' feelings over their responsibilities (Cassidy, Dee, Lam, Welsh, & Fox, 2014; Harris, Froman, & Surles, 2009; Kaplan & Roland, 2018). Cassidy et al. studied the experiences of recitation GTAs who assisted faculty in a first-year, writing-intensive science class, noting that their academic and pedagogical growth was linked to their opportunities to take up multiple roles (e.g., facilitator, liaison, student mentor, faculty mentee, course developer, and scholar). The researchers argued that giving these GTAs complex tasks with weighted responsibilities, rather than menial, procedural tasks, contributed to their identity as instructors and their development of a philosophy of teaching (Bomotti, 1994). Kaplan and Roland made similar conclusions from their work with statistics GTAs. The authors noted that without opportunities to grade students' work and delve into student thinking, the GTAs felt disconnected from the benefits of active learning and indifferent to promoting such instructional methods.

Summarizing issues and recommendations in statistics GTA training. Promoting quality instruction in undergraduate statistics, as in many other mathematical disciplines, is a challenging endeavor that asks much of GTAs and GTA coordinators. "The styles of teaching thought to be most effective place a greater burden on the instructor than simply presenting material" (Moore, 2005, p. 2). Moore hypothesized that such difficulties coupled with priorities on research make teaching reform efforts in statistics departments sluggish or non-existent. Disappointing findings from the 2010 Conference Board of the Mathematical Sciences Report show substantial numbers of statistics GTAs (as well as professors and lecturers) failing to incorporate high-tech tools and foster an active learning environment (Blair et al., 2013).

Pearl et al. (2012) conclude their review of the current research on the PD of statistics instructors with a list of recommendations and research needs. Among topics that ready for research, the authors list questions surrounding (a) instructors' statistical technological knowledge, (b) instructors' views and practices about assessment, (c) effective PD resources for helping GTAs develop knowledge, skills, and dispositions for teaching, and (d) barriers and motivations for GTAs in participating and engaging in PD, among several others. My work contributes to the research gap by providing a foundation from which to understand the disciplinary and pedagogical views of first-year statistics GTAs. My findings also make a case for the experiences and resources these GTAs need in order to adopt the reform-oriented teaching practices outlined by the GAISE Report and by Pearl and colleagues.

Summary

In this chapter, I have reviewed expert conceptions on the nature of statistics, the nature of doing statistics, and a statistical epistemology. These discussions reveal a diverse set of purposes and perspectives from which to view statistics. While viewing statistics as deeply intertwined with mathematics is valid, it is also inadequate to conceive fully the affordances and purposes of the discipline. Statistics is an evolving and multi-faceted discipline which shares characteristics with mathematics and science, but also exemplifies unique characteristics.

Depending on one's desired avenue for participation in statistics, there are various pedagogical aims and recommendations for statistics education. Statistics involves understanding and correctly applying formulas and procedures, but practitioners also appreciate the inferential process, recognize the role of subjectivity and negotiation in statistical problem-solving, and exemplify the many dispositions and modes of thinking that characterize quality statistical work. Furthermore, different students need different kinds of experiences with statistics, with some needing more literacy-focused content that allows them to engage critically with data-based presentations in the media, while others need experiences conducting data investigations and using technology strategically to solve relevant problems. There are many statistically-distinct pedagogical aims in statistics that should be accompanied by unique instructional practices for the discipline.

Finally, I reviewed literature on GTAs to document what the field knows about the content knowledge, disciplinary perspectives, pedagogical views, and experiences of statistics GTAs (and other related groups). These findings demonstrate that many statistics GTAs lack a robust conceptual understanding of introductory content (while often expressing theoretical and mathematical understanding), lack a thoughtful curricular vision for the big ideas of the course, have little to no experience using technology for teaching-related purposes, and have not had a student-centered, technology-rich pedagogy modeled to them. However, many of these GTAs also express desires to foster a student-centered learning environment, but they ultimately lack instructional models and resources to enable that enactment.

My work intends to address many of the themes discussed in the literature and add to our field's knowledge. I first investigate how statistics instructors (specifically, first-year GTAs) conceptualize the purpose of statistics, the nature and development of knowledge in the field, and the practice of doing statistics. I intend to map out the various perspectives these GTAs take and to document various factors that influence their disciplinary perspectives. I also address the clear gap in the literature regarding how statistics instructors' disciplinary views inform their pedagogical views and instruction. In particular, I examine how these GTAs grapple with curricular considerations of an introductory course and whether their disciplinary views inform their initial pedagogical views and teaching practices.

CHAPTER 3

METHODOLOGY

Overview

To study the views and teaching practices of statistics GTAs, I collected data across three semesters. This data collection period included the GTAs' entrance into their graduate program and assistantship roles, two semesters of grading and/or recitation duties, the department's "Teaching-in-the-Discipline Workshop" during semester two, and their first semester of solo teaching the following summer. I approached my data through a multiple case study lens (Yin, 2009) as I made sense of their individual experiences before exploring cross-cutting concepts.

My first two research questions were concerned with framing and investigating the disciplinary views these GTAs expressed about statistics and identifying critical experiences that influenced the development of these views. This analysis resulted in a framework that captured the various perspectives, models, and spectrums of distinction that these GTAs articulated about statistics. I also completed more thorough examinations of each individual's disciplinary views to understand the key influences shaping their views. Next, I examined connections between each GTA's disciplinary views and their views about teaching introductory statistics. My final question considered the instructional decisions each GTA was making in their solo teaching semester and whether these decisions were informed by their disciplinary views. Rather than take their articulated pedagogical views at face value, I wanted to investigate the many factors involved in actually making instructional decisions and interacting with students.

Background

Research design. Outside of Diamond and Stylianides' (2017) examination of the epistemologies of statistics professors, or studies examining the content knowledge of statistics

GTAs (Dolor, 2017; Noll, 2011), sparse research exists that explores the disciplinary views of statistics instructors. Additionally, the field has little research investigating the pedagogical and curricular views of statistics GTAs. While Justice et al. (2017) document the instructional views and practices of GTAs, and Green (2010) and Justice (2017) each offer insight into the experiences of statistics GTAs in their teaching assignments, the field largely depends on studies of mathematics GTAs to fill the gaps. To address this gap in the research, I have chosen to enact a multiple case study design (Yin, 2009). As Yin explains:

> Case study inquiry copes with the technically distinctive situation in which there will be many more variables of interest than data points, and as one result relies on multiple sources of evidence, with data needing to converge in a triangulating fashion, and as another result benefits from the prior development of theoretical propositions to guide data collection and analysis (p. 18).

Consistent with this mindset, my dissertation examined thick data to make sense of the experiences and views of the participants. This methodological lens enabled me to view each GTA as a unique case embedded in their own distinct contextual space (Yin, 2009). The longitudinal nature of the study created opportunity for me to reflect extensively on the data, giving me space to memo, reorient my data collection as necessary, and follow up with participants to explore ideas further (Corbin & Strauss, 2008). Through these affordances, there was a means for findings to arise on their own rather than be forced through a filter of a priori coding categories (Creswell, 2013).

I used existing literature to assemble a skeletal framework for assessing instructors' disciplinary views by starting with four broad dimensions. Similarly, I consulted items and findings from existing research on statistics and mathematics GTAs to inform my own study. For example, research has found it typical for GTAs (and teachers in general) to teach in a manner similar to how they themselves were taught (DeFranco & McGivney-Burrelle, 2001; Kung, & Speer, 2009); as a result, I probed this and other documented phenomena in my questioning. However, I was intentional to leave breathing room for the data to speak for itself and draw attention to things I may not have considered (Corbin & Strauss, 2008). The nature of longitudinal case study research also gave me opportunity to search for nuanced answers. Throughout the study, I reassessed my conclusions as the participants interacted with different tasks and questions across the interviews. In summary, I believe my study offers the most (and possibly the only) detailed findings to date on statistics GTAs' disciplinary perspectives and how those perspectives are reflected in their pedagogy.

Setting.

The department. This study took place at a large public university. The university's Department of Statistics had 200 graduate students, 62 of whom were employed as GTAs. GTAs in this department may be assigned to one of three positions: grader, recitation instructor, or solo instructor. While in many departments, the acronym "GTA" (or "TA") is reserved for positions in which the graduate student is not the instructor of record, this department uses this nomenclature for all graduate students assisting with or solo teaching courses.

Except in rare circumstances, new GTAs are assigned initially to be graders or recitation instructors. Graders are assigned to assist professors for upper-division courses, or occasionally to assist other GTAs who are solo teaching two introductory courses. Recitation instructors assist with one of two large-lecture introductory statistics courses, each with enrollment of up to 500 students. Both courses have two 50-minute lectures per week for all students, taught by the GTA coordinator, and 1 50-minute recitation section held on Fridays, led by the recitation instructors.

Typically, recitation instructors are assigned three 45-student sections and are responsible for facilitating activities and quizzes each week on an alternating sequence. Activities and quizzes (as well as solutions) are created by the GTA coordinator and provided to the recitation instructors. In recitation sections, GTAs answer student questions individually and ensure students complete the activities, but they have freedom to review content and facilitate whole-class discussions if they wish. Other responsibilities include grading quizzes, managing the student gradebook, sending out announcements to their sections, holding office hours, and responding to student emails.

The Teaching-in-the-Discipline Workshop. Typically solo instructor positions are assigned to GTAs who have worked in the department for at least two semesters and who have completed the department's Teaching-in-the-Discipline Workshop. During the time frame of this study the Workshop included 35 participants[2] and comprised six 60-minute sessions weekly during the first half of spring semester. The workshop was led by the GTA coordinator, with content including department-specific policy guidelines as well as activities and discussions related to pedagogy as it pertains to introductory statistics courses. Additionally, a university-wide two-day conference addressed basic information about teaching and school policy; this conference is required attendance for all aspiring solo instructors.

In Table 3.1, I provide a list of the activities and sessions that took place in the workshop during the year of this study. While many of the activities and assignments were the same as in previous years, the GTA coordinator did make some changes for this cycle, based primarily on her own reflections and partly influenced by my suggestions. I met with her three times to

[2] Workshop enrollment was more than double previous years' attendance due to changes in class size being implemented the next year and increased demand for solo instructors in the department. More than half of the participants were not current GTAs, while in previous years, almost all participants had been current GTAs.

discuss the workshop and brainstorm about elements she wanted to revise. Overall, I judged my influence to be minimal, and I would not deem any of the activities and assignments that took place as being atypical for a statistics GTA training workshop. This is not an exhaustive list of workshop components, but this does address substantive sessions and assignments.

Table 3.1. *GTA Workshop Elements*

Week	Segments and Small Group Discussions	Assignments
1	*GTA Canvas Site Introduction:* GTA Coordinator presented course website that includes resources for the workshop and for solo teaching. *Qualities of a Good Statistics Instructor*: In groups of 4, Students wrote down three qualities of a good introductory statistics instructor, with each group sharing one item with the class.	*Classroom Observations (Ongoing)*: Students need to visit at least two different instructors' classes over the following weeks and answer a short observation protocol for each about what they liked and did not like about the class.
2	*Data Collection Activity:* Students recorded how many keys they had with them on class dotplot. Students then got in groups of 4 and reported average number of keys on second dotplot. GTA Coordinator used as example of active participation and use of real datasets. *Grading Components*: Students were provided a list of common assessments (e.g., exams, attendance, homework, projects, etc.) and asked to think through how they would structure their grading components across various options. Short discussion followed.	*Read "The 10 most common teaching mistakes:"* Students assigned to read 5-page essay about promoting quality instruction at the undergraduate level.
3	*Administrative Details:* GTA Coordinator discussed department and university teaching policies. *Pacing Schedule Activity:* In groups of 4, Students filled in 30 class periods of content using the GTA Coordinator's pacing schedule as a guide, including assessments and activity titles. *Email Courtesy:* GTA Coordinator provided handout with tips on writing courteous and appropriate emails. In groups of 4, Students had opportunity to think through response to sample student emails.	*Write Syllabus*: Students asked to write a syllabus aligning with one of the introductory courses, including required syllabus elements and their own preferences regarding grading components or classroom management guidelines.
4	*Syllabus Grading:* Students swapped syllabi and completed checklist for required elements. *FSU Policies Quiz:* In groups of 4, Students completed a multiple-choice quiz on proper policy for different teaching scenarios and student issues. Students asked to think about how well their syllabus addressed many of these issues.	
5	*GAISE Report*: GTA Coordinator discussed the Executive Summary, sharing examples of how to address each of the six guidelines. Special note that the GTA Coordinator left guideline	

Table 3.1 – continued

Week	Segments and Small Group Discussions	Assignments
5	1 (teach statistical thinking) for last and did not discuss; remarked that she was wanting to improve on this one and think through how to apply it in her own course. *Question Writing Activity:* In groups of 4, Students were provided list of data points with corresponding boxplot and histogram and asked to write conceptual questions they could ask using this information. Briefly discussed together. *Grading Activity:* In groups of 4, Students discussed how they would grade a sample student quiz. At the conclusion, the GTA Coordinator briefly discussed how she would grade the quiz.	
6	*Mindfulness scenarios: G*TA Coordinator opens up segment asking students what they would do if no one is talking or listening. After short discussion, handout is passed around with four questions about keeping energy, how to prepare when you do not want to go teach, and what they like (or is least unlikeable) about teaching. Students discuss in groups of 4. *End of Workshop Survey:* Students individually fill out survey, assigning scores to different workshop segments and assignments as well as free-response summary items.	

Participants. Participants were drawn from a new cohort of graduate students in the department of statistics who had been awarded teaching assistantships. All new graduate GTAs were contacted for inclusion in the study and requested to complete an entrance survey online and a one-on-one interview with me. Of the 12 new GTAs, 7 of them chose to complete entrance surveys and interviews. Demographic information is provided about the 7 GTAs who completed entrance interviews in Table 3.2, with those who participated the entire length of the study bolded.

Table 3.2. *Initial Pool of Participants*

Pseudonym	Nationality	Degree Program	Teaching Experience	Highest Degree
Kathy	**U.S.**	**PhD**	**Undergraduate TA**	**B.S. Math & Health**
Brad	U.S.	PhD	Graduate TA, Lecturer	M.S. Statistics
Wei	Chinese	PhD	None	M.S. Statistics
Li	**Chinese**	**PhD**	**None**	**B.S. Math**
Mindy	**U.S.**	**Masters**	**None**	**B.S. Math**
Sahil	**Indian**	**PhD**	**None**	**M.S. Statistics**
Dennis	South Korean	PhD	None	B.S. Math

As the year progressed, the pool of participants was narrowed to four GTAs who would all be assigned for solo teaching the following summer. Since Brad had formerly taught as a visiting lecturer at a different institution, he received a solo teaching position in the spring; for this reason, I viewed his instructional path as quite divergent from the others. After the second interview, Dennis and Wei each stated that they did not intend to be solo instructors, so no further data collection was completed with them. Of the remaining four GTAs, Kathy and Mindy were eventually assigned to be the online instructors to replace the two current online instructors who were leaving the department the following year. Li and Sahil were each assigned in-class solo positions.

Each of the four remaining GTAs provided unique perspectives worth studying. As became clear in the initial interview, Kathy and Mindy had similar previous experiences (B.S. in mathematics, internship experience, etc.) but different aspirations. Kathy was initially hoping to complete a PhD and become a pharmaceutical researcher and possibly a professor one day. Mindy was completing the 1.5-year M.S. program in Data Science, desiring to work in industry. They also completed different recitation assignments the first year, with Mindy working with the GTA Coordinator and Kathy assisting with a different introductory course with another statistics professor. Sahil was also a recitation instructor for both fall and spring, but he came in with a 5-year degree in statistics from India. Li had a B.S. in mathematics from China before joining the department. Unlike the others, he worked as a grader during the fall before being assigned to recitations in the spring. He also struggled with English more than the others, being required to take an English proficiency course in the spring to meet necessary qualifications to be a solo instructor.

My role. In my role as a researcher, I had to think carefully about the influence I would have on the participants and their department environment (Maxwell, 2013). As discussed in Chapter 1, I recognize this work as accounting for both a natural, contextual influence on GTAs' disciplinary and pedagogical views in addition to influences I exerted into their narrative. By asking certain questions or presenting certain survey items, I introduced ideas that GTAs may not have otherwise considered. For example, one survey item asked participants how much they agreed or disagreed with the following statement: "Students should learn to carefully judge and evaluate data-based arguments and claims they see in the media." By presenting that idea, GTAs were introduced to a perspective on introductory courses they may not have heard before. Additional questions (e.g., "Is data objective?") likely prompted them to consider why this is a question worth asking, suggesting that others might disagree. I recognize this as a limitation to probing views that are not solidified beliefs; GTAs may hold a certain view, not because they have carefully weighed the alternatives, but because they are unaware that alternatives exist.

As someone who was likely perceived as a more knowledgeable other, my views (to the degree they were transparent through my choice of words, tone, and body language) were potentially taken up as correct or ideal. To some degree, my presence was not unlike a GTA mentor in creating a space for new GTAs to share their experiences and reflect on their own practice. However, my role was unlike a GTA mentor in my choice to avoid giving substantive advice or talking about my own views or teaching practices explicitly. When in the same room as the participants, it was important for me to be conscious of my words and body language cues to minimize my influence as much as possible. During the workshop sessions, I strove to present a friendly demeanor, engaging in casual conversations with the GTAs as appropriate, but I positioned myself as a quiet observer during teaching discussions and activities. Thus, during all

GTA interactions, I refrained from commenting and giving opinions about the department training, professors, or the GTA coordinator's instruction and instructional materials.

In analyzing the data, I strove to see beyond superficial acceptance of ideas and delved into GTAs' deeper views about teaching, which included triangulating findings with their actual teaching practices. It was important to ensure that my claims were rooted in the data rather than in transferring my own experiences on others. Intentionally comparing my participants' experiences with my own was a critical step in keeping these differences clear and distinct.

I realized quickly that keeping a strictly professional relationship with each one might present more drawbacks than advantages. "It is not distance that qualitative researchers want between themselves and their participants, but the opportunity to connect with them at a human level" (Corbin & Strauss, 2008, p. 13). I noticed that engaging in casual conversation before and after the interview opened the participant to talk about several experiences they did not discuss while the camera was on. After the first interview, I made it a habit to begin each subsequent interview with space for casual conversation, delving into each person's story with open curiosity so long as they were willing to share. This intentional change in the nature of our relationship was often tricky to navigate as the lines between research participant, acquaintance, and even friend became blurred. As participants opened up about themselves, I welcomed the opportunity to get to know them better.

As Corbin and Strauss (2008) explain, "We don't separate who we are as persons from the research and analysis that we do. Therefore, we must be self-reflective about how we influence the research process and, in turn, how it influences us" (p. 11). I often found myself in tricky situations where I had to decide what kinds of things it was okay to discuss casually, or whether it was ethical to remain silent when a participant encountered problems. One such instance came up in an observation of one GTA's class during the teaching semester. An instance of miscommunication by both the GTA and the students brought about mixed-up labels for left and right skewed distributions. When it appeared that instruction had moved on and students had clearly written the wrong labels down, I felt empathy for the instructor as well as concern for later confusion on the part of the students. I decided to point out the mix up on the board, but I reflected later that I probably should not have done that. I strived from that point on to be very careful and intentional about how I would react or respond to teaching-related issues.

Despite a handful of moments across this study where I perceived I crossed the line, I believe the close nature of my relationship with many of the participants was an advantage. I got to know each of these GTAs as people, and we developed trust and transparency in our relationships. Since the aims of this research were not to report the social and emotional development of these GTAs, I see no apparent validity concerns stemming from the nature of my relationships with the participants, given that I was careful to document how my contributions potentially influenced their disciplinary and pedagogical views.

Data Collection

In this section, I discuss the data I collected for this work. Table 3.3 presents a data collection timeline, which is then followed by a description of the data sources.

Surveys. GTAs took surveys at three timepoints across the data collection timeline. Participants completed Survey 1 (S-1) twice (when they entered the department and again as they began their solo teaching semester), while Survey 2 (S-2) was completed at the end of their solo teaching semester. S-2 contains many of the same items from S-1, but with minor changes (e.g., tense change, additional items for reflection). The surveys are included in Appendix B.

Table 3.3. Data Collection Timeline

Timing	Data to Collected and Measures Used	Purpose
September	S-1: Entrance survey I-1: Entrance interview	Learning about participants' previous experiences and initial views about statistics and statistics teaching.
December	I-2: First-semester check-in	Documenting participants' first semester experiences as GTAs and graduate students; completing the Statistics Mind Map Activity.
January-March	Artifacts from workshop Field notes	Documenting the activities and assignments participants completed and the experiences they had.
March	I-3: Post-workshop reflection	Exploring participants' workshop experiences and reflections; targeting their epistemologies with depth.
May	S-1: Pre-teaching survey I-4: Pre-teaching interview	Documenting participants' experiences planning for first solo teaching assignment and assessing their proposed course structure and materials.
Summer	Field notes/Classroom Videos/Email Exchanges/ Course materials	Observing/Documenting GTAs' classes/discussion boards; referencing course material and chosen quiz/exam questions for possible discussion in forthcoming interview
June/July	I-5: Mid-teaching check-in	Checking in with GTAs during the semester to ask questions about their experiences and learn more about particular pedagogical decisions they make.
End of Summer Term	S-2: Post-teaching survey I-6: Post-teaching reflection	Documenting GTAs' overall teaching experiences, capturing their current epistemologies, assessing how their pedagogical views have been reinforced or evolved.

S-1. To develop S-1, I consulted both the Statistics Teaching Inventory (STI) (Zieffler, Park, Garfield, delMas, & Bjornsdottir, 2012) and the Graduate Student Statistics Teaching Inventory (GSSTI) (Justice et al., 2017), using or adapting many items from each that were relevant to my goals. I also wrote several of my own items to cover areas that I felt were lacking (e.g., items assessing the aims and content of an introductory statistics course; items about general pedagogy, such as the perceived effectiveness and prominence of lecture, etc.). All items, with specific highlighting of newly written items, were reviewed by four professors with expertise in GTA training and thinking—three of those four experts had experience specifically in statistics GTA training. Feedback was conducted iteratively, with a round of revisions being made before passing along the items to the next expert. The survey items as they appear in Appendix B reflect the final iteration.

S-2. S-2 is almost identical to the first survey, but with changes in tense for some questions (to reflect GTAs' having already taught as solo instructors) and several added items to allow for reflection across the semester. These items were again inspired from the GSSTI and STI and phrased to reflect GTAs' perceptions of what actually happened in their course.

Interviews. While the surveys provided general insight into participants' pedagogical views, the interviews provided deeper understanding of underlying motivations and influences, including more detailed pictures of their disciplinary views. I assessed certain key ideas spirally across interviews while slightly varying tasks to ensure a fresh perspective each time. Table 3.4 displays content summaries for each interview. Interviews took place at critical points in the year, allowing me to probe their reflections to different important experiences. But in addition to probing experiences, I also posed tasks and other complex questions in these spaces. In the following sections, I describe the substantive tasks and question themes that characterized the interviews. Full interview protocols are included in Appendix D.

Statistics mind-map task. This task, which appears in the second interview, was designed to capture a visual perspective of the participants' views on the nature of statistics, and to also get a glimpse of their curricular views. First, participants were asked to create a word wall listing terms, phrases, or ideas that they associated with the discipline of statistics. From there, they attempted a first draft of a mind map on paper that showed similar ideas subsumed under broader terms; participants took this up either as a flow-chart or as a Venn diagram. Discussion of the

Table 3.4. *Summary of Data Collection*

Interview	Experiences	Disciplinary views	Pedagogical Views (Intro-Course Specific)	Pedagogical Views (General)
I-1: Late August	Reflection on being student, tutor, or teacher previously	Basic Disciplinary Questions	Reflection on goals of introductory statistics course for non-majors; S-1 items	Reflection on general pedagogical views (e.g., how they would be similar or different to previous instructors); S-1 items
I-2: December	Reflection on first-semester of courses and assistantship duties	Statistics Mind-Map Task	Pedagogical views relating from discussion of first-semester GTA experiences; Statistics Mind-Map Task	Pedagogical views relating from discussion of first-semester GTA experiences
I-3: Late March	Reflection on GTA workshop	Disciplinary Dimension Questions	Pedagogical Questions	Discussion of Workshop Activities and Assignments
I-4: First solo teaching week	Reflection on planning for first solo teaching semester	[None]	Course Objectives/Learning Goals Task; S-1 items	Course Objectives/Learning Goals Task; S-1 items
I-5: Fourth solo teaching week	Reflection mid-way through first solo teaching semester	Probing disciplinary perspectives/content knowledge related to teaching topics;	Follow-up on classroom tasks, assignments, and/or assessments	Follow-up on observations/documentation of teaching/discussion boards
I-6: Week after course finishes	Reflection after first solo teaching semester	Probing disciplinary perspectives/content knowledge related to teaching topics; Follow-ups from previous interviews	Pedagogical Questions; S-2 items; Follow-up on classroom tasks etc.	S-2 items; Follow-up on observations etc.

resulting map allowed for more insight into how the participants structured the discipline of statistics and conceptualized core elements of statistical practice. Some maps also provided insight into their curricular views by representing a logical ordering to learning certain disciplinary elements.

Course objectives and learning goals task. For this task, I wanted to capture GTAs' views about the aims of an introductory statistics course. Participants were first asked to list the skills and understandings they wanted students to have by the end of their introductory course. This prompt was open, allowing participants to list both specific and general ideas, as well as questions they wanted their students to answer. Participants were then asked to describe the progression of their course and how or in what order these goals would be accomplished. If a participant gave a more topic-wise response to this question, I probed to see if they could visualize their course beyond simply a list of general topics. For example, I asked whether topic ordering matters, if they saw any topics building on one another, if certain key ideas or themes streamed through multiple topics, or if there were any foundational ideas that they saw their course building from.

Next, the participants were presented with nine slips of paper, each listing a potential introductory course objective. These objectives represented either objectives specifically recommended by the GAISE Report, or topics that GAISE suggested for omission (ASA, 2016). The participants were asked to take one away that they viewed as least important, continuing to take one away from the remaining objectives until they had implicitly created a hierarchy of least to most critical objective. Next, they were presented with 17 slips of paper listing potential learning goals (more specific than objectives) that they placed in one of three categories according to perceived importance. I wrote each of these learning goals, with some representing goals I noted from the GTA Coordinator's course, some representing goals I had observed in other GTAs' courses, and some representing goals that aligned with the GAISE Report. After sorting, I asked the participants to revisit their written course goals, reflect on alignment between their written work and their sorting results, and discuss which objectives and goals they believed would be most challenging to address in their course.

Disciplinary-dimension questions. Using the four dimensions outlined in my conceptual framework, I compiled questions aimed at revealing GTAs' disciplinary views. These questions were influenced by and adapted from items from epistemological questionnaires in the literature (e.g., Baxter Magolda, 1992; Diamond & Stylianides, 2017; Liu & Liu, 2011; Tsai & Liu, 2005). I compiled original, adapted, and new items to fulfill the purposes of my work and align with my own framing, as discussed in Chapter 1. I refined these questions again after piloting them using think-aloud interviews with two experienced statistics GTAs.

While a comprehensive set of questions was used for I-3, I only used a generic subset of the disciplinary questions (e.g., "How would you define statistics?" and "What do you think it means to do statistics?" and "Why should undergraduate students in non-mathematical majors take introductory statistics?") in I-1 for two reasons. First, I judged the comprehensive set of questions to be too overwhelming to pose given the potential for some new GTAs to have little to no previous experience in statistics. Second, I was concerned that addressing these issues too early might push them to articulate perspectives and positions before they were ready, effectively disrupting the responses from developing naturally as the GTAs completed their first two semesters of graduate work. I chose instead to introduce these more rigorous questions midway through the GTAs second semester in the program, providing opportunity for the GTAs to self-report on whether their views have been influenced during their time in the program.

Pedagogical questions. I also developed a set of pedagogical questions that were posed primarily at the conclusion of I-3. These questions focused on three key themes. The first theme addressed knowledgeability and expertise in statistics. I intended for this theme to inspire a discussion about whether students in the introductory courses could ever be considered knowledgeable in statistics, and what experiences or content knowledge they would need to get to that level. The second theme accomplished a similar purpose by probing participants to think of different ways that one might participate in statistics, leading inevitably to a discussion about how or whether introductory students might participate in statistical work. The third question reflected a general pedagogical theme: the different ways that a statistics instructor may facilitate learning and knowledge building.

Additional interview data. The interviews acted as linchpins in the data collection process, serving as a timely follow-up to the experiences GTAs had across their assistantship. For example, interviews provided an opportunity to inquire about response changes on the survey across attempts, to revisit assignments and tasks that participants completed as part of the department teaching workshop, and to follow up on teaching observations during participants' solo teaching semesters. For this reason, my first few interview questions served as conversation starters that provided a space for the participants to reflect on their ongoing experiences. These reflections were critical to understanding the basis of their views regarding the nature of statistics, disciplinary engagement in statistics, a statistical epistemology, and their relation to teacher beliefs (Luft & Roehrig, 2007; Russ, 2014).

Workshop artifacts. GTAs completed several tasks and assignments as part of their participation in the teaching workshop. Assignment artifacts collected include their listing of qualities for a good introductory statistics instructor, their classroom observation sheets, their syllabus, and grading component outline, and their question-writing activity. I took field notes to account for interesting exchanges or moments as well as to describe the mood and general engagement of participants. During small-group discussions, I occasionally recorded statements from my four participants that revealed important insights about their disciplinary and pedagogical views. These notes were helpful as a source of triangulation when I asked the participants about their workshop experiences.

Observations. During their solo teaching semester, I encouraged Li and Sahil to make 2–3 minute audio or written reflections after each class that I would not collect. These reflections were intended to encourage them to reflect on each lesson and document these reflections in an easily accessible format. To structure their reflections, I provided a reflection template containing five things they might choose to address: “What we covered today,” “What my goals were today,” “What went well,” “What didn’t go well,” and “Anything I wish I did differently or want to improve on next time I teach.” In the end, neither remembered to complete these reflections. However, both were rather consistent in speaking with me often about their teaching, even outside of the interviews. These informal conversations were not codified data, but they did allow me to remain aware throughout their course of their experiences, which I would memo. These memos helped me remember certain conversations and pose questions in the subsequent interviews related to these points.

I also visited six of Li and Sahil’s classes (three observations between I-4 and I-5, and three between I-5 and I-6) to observe their teaching and classroom facilitation on business-as-usual days. I was able to record 5 out of 6 of these observations for each one, allowing me to go back and create transcripts for key classroom interchanges between the instructor and students. Since I knew each GTA might be tempted to prepare specially for observation days, I simply told them that I planned to visit or have recorded one class a week, and to let me know if there was any day that would not be suitable for observation (e.g., an exam day). For each observation, I took field notes intended to capture the nature of student engagement, the statistical content being addressed, what I perceived as the goals for the class, the nature of instructor's responses and interaction with students, the nature of the problems the instructor presented to students, and any other things that struck me as noteworthy. I also utilized the Classroom Observation Protocol for Undergraduate STEM (COPUS) (Smith, Jones, Gilbert, & Wieman, 2013) to provide a more objective measure of how GTAs structured their classes in terms of lecture, group work, student talk, and a variety of other classroom events.

With Kathy and Mindy teaching online sections, observation and documentation proved more challenging. For their classes, I was granted access to their course Canvas sites, allowing me to see announcements, course resources, and discussion board postings. Each of them also agreed to forward me de-identified email exchanges with students over content-related questions. In the end, as I discuss in more depth in Chapter 6, there was little to report on this front. In-person visits from students were sparse for Mindy and Kathy, the only discussion board post from a student was to report a typo in a question, and essentially every student email received was related to using the calculator, using the homework platform (Launchpad), or asking if a topic would be on the Final exam. Because of the limited data I received about their teaching, I answer my fourth research question primarily regarding Li and Sahil, while offering only brief analysis and thoughts about Mindy and Kathy's online teaching reflections.

Administrative documentation. In addition to the data listed at specific timepoints across Table 3.2, I also collected data from GTA meetings that took place across the year and emails sent to GTAs regarding teaching responsibilities. For each GTA meeting, I also collected a copy of each handout and took field notes of meetings (when I could be present) to keep a record of what happened in the meeting. Most of these meetings covered course policies (e.g., if a student asks to take the Final Exam on a different day, handle it like this) and allowed the GTA coordinator to touch base with GTAs about their responsibilities. Emails accomplished similar purposes in simply reminding GTAs of things needing to be done as the time comes or informing GTAs of changes. These data were helpful for clarifying or triangulating interview responses.

Data Analysis

In this section, I discuss how I analyzed my data to answer the four research questions. The first and second questions were addressed through a similar analysis, with the first resulting in a framework, and the second resulting in specific case profiles. The third question examined key pedagogical views that emerged from each of the participants, which I connected to their disciplinary views. Finally, the fourth question addressed findings from the solo teaching semester, where I make sense of their instructional decisions in light of their disciplinary views, pedagogical views, and ongoing experiences.

Examining each GTA's disciplinary views and constructing a disciplinary framework. My first two research questions were addressed through triangulation across a wide variety of data sources. Questions in I-1 captured GTAs' incoming views and thoughts about the identity of statistics as a discipline and how they initially saw their role as future disciplinarians. The statistics mind-map task in I-2 served a similar but distinct purpose by allowing the participants to explore what ideas they associated with statistics and how these ideas related. Data from these two interviews provided a general foundation for their disciplinary perspectives that was addressed in more depth in the subsequent interviews. More complex disciplinary questions in the second semester pushed each GTA to consider more nuanced positions about the distinctness of statistics, the structure and context of statistical knowledge, the means of negotiating and justifying statistical knowledge, and the ways of engaging in statistical work. Throughout the year, I had ample time to memo, reflect, and synthesize responses. Often my memos took the form of case profiles of each GTA as I made sense of their views and experiences. Follow-up questions in I-4 and again in I-6 allowed me to test ideas and enhance the validity of my claims.

To analyze the data, I first isolated the first-semester data (including I-1 and I-2) as a means of creating initial profiles of the participants. I created a data matrix (Miles, Huberman, & Saldaña, 2014) that included all statements GTAs made regarding past experiences, separated by participant. I then created categories of experience to more easily compare statements across GTAs. Identifying similar types of experiences was helpful in comparing and contrasting the role of these experiences in each GTA's formation. For example, GTAs' recall of their former professors was a shared experiential category, but these experiences were widely variable among the GTAs and had strikingly different contributions on their disciplinary and pedagogical views. Next, I created another data matrix for each GTA separately that included both experiences the GTA discussed and general disciplinary views elicited. After making these data matrices, I wrote summaries of each GTA to synthesize and compare these early profiles, as well as to describe connections they explicitly made or that I inferred between their experiences and disciplinary views.

I-3 included the more comprehensive disciplinary dimensions questions. While certain questions were written to assess their views in certain dimensions, I later found a more open-coding approach (tagging responses from any question to certain dimensions) as more sensible. As I began compiling statements and views under each dimension, I also open-coded for concepts (Corbin & Strauss, 2008). Some of these concepts followed directly from certain questions I asked, while some emerged more unexpectedly from several participants. Identifying these conceptual categories helped me compare and contrast views from each participant.

Throughout this process, I tried different frames of distinction as I considered how the participants were expressing their disciplinary perspectives, resulting in various spectrums of distinction and models to represent their views. These models and spectrums were continually refined as I analyzed data through I-6. I continued this process until I felt the spectrums and models I had created represented all of the data well and could be traced consistently through the participants' responses, reaching what Morse (1995) defines as data saturation. The resulting models and spectrums are displayed throughout Chapter 4 in Figures 4.1, 4.2, 4.4, 4.5, and 4.6.

Moving to the case-study component of this analysis, I continued to write and refine case profiles for each participant regarding their disciplinary views across each dimension. I also considered Roth and Jornet's (2014) components of experience as a guide for identifying noteworthy moments or recollections. I considered whether the experience carried power and notability in the GTA's mind, resulted in an affective response, and/or produced a transformation in thinking or perceiving. However, most experiences were recalled by the GTA (e.g., reflections on previous instructors, an interaction with a student) rather than witnessed by me first-hand. Thus, deciding if an experience was meaningful largely relied on each GTA's self-report. Additional probing often clarified how certain articulated views linked to experiences and recollections they had.

By meeting with these GTAs over the course of a year, I was able to construct and test explanations about how each GTA's experiences related to their disciplinary views (Corbin & Strauss, 2008). I often shared my tentative explanations with each GTA (in the moment or at a later interview) and received confirmations or rebuttals based on their own perceptions. In such cases, I would often attempt to reword a GTA's reflection or view and ask if I was capturing their thinking. The GTA could then affirm or refine my statement. It was through a series of such interchanges that I was able to come to explanations about each GTAs' views with some fidelity.

The surveys primarily contributed as a window to discover interesting (or sometimes conflicting) stated views. Other data outside of the interviews and survey responses were also referenced as applicable. For example, email and GTA meeting documentation were available as a means of follow-up or triangulation to participant statements about experience. By collecting information about each GTA meeting, I was able to document potentially relevant experiences for GTAs. I also considered the experience of the interview and surveys themselves, being intentional to ask GTAs to reflect on the tasks they completed and questions they answered, probing whether they felt their views had changed or shifted by thinking about a particular idea.

Connecting disciplinary views to pedagogical views. My third research question considered how GTAs' disciplinary views connected to pedagogical views for an introductory statistics course. Some of my interview questions inquired about their general experiences with teaching and learning, while other questions (primarily those in I-3 and I-4) probed their pedagogical views stemming from deeper epistemic and disciplinary perspectives (e.g., "Can someone at the level of your introductory students be knowledgeable in statistics?"). Also, the surveys and survey follow-ups in the interviews probed more fine-grained issues like course-structuring details, curricular decisions, grading components, the nature of teacher–student relationships, and priorities regarding the content and skills to be privileged. This variety of data sources again helped with triangulation, with reflections and follow-ups in I-5 and I-6 helping me to reach saturation and resolution on my conjectures.

The course-objectives task in I-4 was central to revealing how GTAs were grappling with many of the pedagogical-dimension items by pushing them to rank goals. In this task, participants were asked to list their own learning goals for students, followed by ranking a set of provided course goals and objectives. My follow-up questions further probed their choices in privileged objectives and learning goals to reveal their vision for knowledgeable and prepared students and what activities and tasks would facilitate learning and disciplinary participation. The mind-map task from I-2 provided visual insight into these issues as well, since they often related their ideas about statistics to the content that would appear in a statistics class. For example, Kathy explicitly related her mind map to the progression and goals of an introductory course. Additionally, the ordering and clustering of topics in the mind map task naturally bridged the pedagogical with the disciplinary.

Data from the teaching workshop was key to understanding how initial views for teaching were translated into more specific commitments as the GTAs completed activities for assigning percentages to various assessment categories, brainstorming qualities of a good introductory statistics instructor, and writing a syllabus. I-4 provided opportunities to assess how each GTA had more or less settled on the structure of their course heading into their teaching semester.

My analysis began with exploring common perspectives and views across the participants. In documenting my findings, I instinctively divided the participants' curricular views from their views about teaching and learning. I found curricular views to commonly stem from experiences in the department (e.g., the GTA Coordinator's notes), while teaching and learning views were closely related to their experiences as students in their own graduate courses. Overlap between these categories became more apparent during their solo teaching semester; however, I found this distinction to be helpful in my initial analysis of their pedagogical views prior to their solo teaching.

I then moved from a cross-case perspective and focused on developing the pedagogical profile of each participant. To link the participants' pedagogical views to their disciplinary views, I consulted their mind maps and subsequent discussions closely to understand how their pedagogical views were linked to their visions of statistics. I also consulted the disciplinary profiles I wrote of each participant to identify connections. Additionally, I aimed to understand external influences on their pedagogical views that may or may not be linked to their disciplinary views. Changed responses on identical survey questions signaled potentially important movements based on department experiences, upon which I could follow up during interviews. Explicit discussions across the interviews allowed me to test ideas and come to resolution on their curricular and instructional vision for introductory statistics.

Understanding GTAs' instructional motivation. My final research question was intended to explore the implications of GTAs' disciplinary views on their teaching practices. To answer this question, I relied on data I collected from the actual classroom observations and course-website monitoring that would inform follow-up questions during I-5 and I-6. The interviews provided insight into whether the participants' disciplinary commitments seemed to be guiding their course decisions, or whether these disciplinary commitments were being overruled or even reshaped by other influences.

Since Mindy and Kathy were each assigned to lead online classes (which involved only overseeing students' progress in the online program "Launchpad"), I was only able to observe and analyze Li and Sahil's teaching. For Li and Sahil, I started with reviewing COPUS coding results to see what proportion of class time was devoted to various instructional strategies (e.g., lecturing, answering questions, facilitating discussion, facilitating activities, etc.). This broad view of the classroom provided a helpful starting point to considering the role of the instructor. I also took field notes to provide a more qualitatively rich description of classroom norms, the content of student–teacher talk, and other aspects of instructional strategies that may not be captured by COPUS. With the aid of video recordings for each class, I was also able to go back and transcribe key student–teacher interactions.

For all participants, the survey at the end of their teaching semester served as a reflection for them to consider their current pedagogical views (allowing me to see whether there was a change) and how well they felt they accomplished many of these goals in the semester. Revisiting the survey responses in the interview helped clarify whether the GTA saw their pedagogical views in tension with their teaching practice, or whether they regarded their own initial views as simply naïve and uninformed. Additionally, the interviews served as a helpful opportunity to collect teaching reflections. In the case of Li and Sahil, I was able to ask follow-up questions to probe discrepancies between my observations of their classes and their expressed intentions and pedagogical views.

Transcripts from I-5 and I-6 were open coded to identify points of divergence from the participants' previously articulated disciplinary and pedagogical views. I recognized many of these divergences in the interview, at which point I would inquire further about these seeming discrepancies. After the interview, I refined my explanations to map certain experiences and influences to these conflicting practices, following up with each GTA as necessary to refine my conjectures. These moments provided the opportunity for the GTA to consider whether they believed their articulated views aligned with their teaching, or if they simply recognized additional constraints and influences at play in their teaching decisions. A cross-case synthesis elicited commonalities and distinctions across participants, prompting me to conjecture what influences other than disciplinary views could be guiding their decisions.

For Li and Sahil's instruction, I collected in-class activities and worksheets (and accompanying solution keys) from classes I observed, in addition to a handful of tasks I received from them from other classes. As a last stage of my analysis, I analyzed these tasks to test and refine many of my conjectures. I ultimately developed two coding categories that reflected themes from the interviews. The first theme, openness and flexibility, assessed how much of the work students were asked to complete was procedural and close-ended and how much allowed for flexible approaches and substantive decision-making by the student. The second theme, contextual integration, assessed what role (if any) context played in the task.

I created four levels within each category, ranging from 0 to 3, and refined these descriptions as I initially coded several activities. I then discussed the codes with another statistics education researcher as we coded two tasks together. We then coded four tasks independently (comprising one-third of the tasks collected) and compared. We matched on 2 out of 4 decisions on openness and flexibility and achieved the same average score (1.5); we matched on 3 out of 4 decisions on contextual integration, making my average 1.25 and his average 1.5. After discussion and resolution over our disagreements, I coded the remaining tasks independently. The reader will find a comprehensive coding framework in Appendix D; abbreviated descriptions of each code appear in Table 3.5 and Table 3.6.

Validity

In his discussion of establishing validity in qualitative research, Maxwell (2013) lists eight different validation strategies. These include (a) intensive, long-term involvement, (b) rich data, (c) respondent validation, (d) intervention, (e) searching for discrepant evidence and

Table 3.5. *Openness and Flexibility of Task*

Level	Description
0	Over 90% of the task involves only procedural, close-ended questions and instructions
1	The task includes isolated opportunities for quasi-open-ended responses (students are expected to model their responses using fill-in-the-blank-style phrases from the notes)
2	Task includes frequent opportunities for quasi-open-ended responses OR isolated instances for rich, open-ended responses that have no phrase guides in the notes
3	The task includes frequent opportunities for rich, open-ended responses

Table 3.6. *Contextual Integration of the Task*

Level	Description
0	The task involves no contextual setting
1	The task involves context that is unclear OR the context does not affect how students engage in the task
2	The task involves context that both is clear and pushes students to think about contextual implications beyond simple fill-in-the-blank or short answer conclusions
3	The task matches the characteristics of level 2, but also includes opportunities for students to openly discuss the context, explore the data through multiple visuals, or make design decisions that respond to the nature of the context

negative cases, (f) triangulation, (g), numbers, and (h) comparison. I briefly discuss how my research integrates many of these validation strategies.

By observing, interviewing, and interacting with the participants for a full year, I was able to have prolonged engagement with the participants. By conducting six different interviews and observing the GTAs in meetings, workshop sessions, and (in the case of Li and Sahil) the classroom, I viewed the participants in many different settings. I also had time to develop conjectures during the year that I could test and refine. The quality of my primary data typically involved rich accounts, as I had video recordings for each interview and several video recordings of Li and Sahil's teaching. Additionally, this design allowed me to collect many facets of data to establish thick descriptions and accounts. These varying data sources allowed me to triangulate findings. I was also able to present conjectures and interpretations to the participants in later interviews to establish a certain level of respondent validation (Creswell, 2013; Guba & Lincoln, 1994). Having four cases created natural comparison between the participants. Particularly with Mindy and Kathy, I noted early in the research that the two articulated very similar classroom visions (e.g., students should work through problems in class) forcing me to look for nuanced differences. Seeking inter-rater reliability with regard to Li and Sahil's classroom tasks provided a check on my analysis to see whether my conjectures about their instruction were readily seen by another.

I also worked to establish a level of validity to my survey and interview items through expert reviews, pilot interviews, and inclusion of validated survey items where appropriate. Using items from the STI, GSSTI, and Justice's (2017) study, in addition to some of my own items, I made iterative revisions to the survey by gathering expert feedback and completing pilot interviews with current international GTAs in the statistics department. I made the first revisions after engaging in a careful discussion with a faculty member who possessed extensive experience researching and working with statistics GTAs. I then administered the current survey to two current international GTAs in the statistics department, with revisions made after each interview. These pilot interviews provided insight into wording issues and potential misinterpretations by non-native English speakers. Finally, I sought feedback from three experts on this newest survey draft, with drafts iteratively revised and presented to each expert in succession. Each of these experts had considerable research experience with GTAs, two in statistics specifically and one in mathematics. Some reviews focused more on tasks while others focused more on potential interview questions.

The interview questions followed a similar process of review. The original set of questions and tasks I created were presented to three statistics education researchers for review and discussion, with many closely adapted from existing interviews used in the literature. The disciplinary dimension questions were compiled later and reviewed by a science education PhD student with knowledge and experience in GTA professional development and beliefs, a science education faculty member with extensive research experience in epistemology and disciplinary engagement, and a statistics education faculty member. For all questions and tasks, I made changes after each expert's feedback, with drafts iteratively revised and presented to each expert in succession. For example, the course objective task was reorganized and new objectives and learning goals were added/reworded based on feedback. Interview questions were revised for clarity and precision in goals, and open starter questions with potential follow-up directions were added. Interview components were also assessed in terms of how they aligned with my research goals and clarity in presentation. The survey, the statistics mind map task, the course objectives/learning goals task, and the disciplinary dimension questions were each piloted to two experienced Chinese statistics GTAs and one Indian statistics GTA. From the pilot interviews, I made changes to the ordering and wording of some tasks and questions, mostly by adding more scaffolding to the question to ease the transition to deeper ideas.

CHAPTER 4

DEVELOPING A DISCIPLINARY FRAMEWORK FOR STATISTICS

This chapter organizes findings from my first research question: “How might a framework be used to organize the various disciplinary perspectives and tensions that first-year statistics GTAs grapple with?” To develop this framework, I provide examples from several of the participants that clarify how these perspectives and tensions emerged from the data. More detailed quotes and analysis of the participants’ disciplinary views are located in Chapter 5, which presents case narratives that closely address the second and third research questions.

As discussed in the previous chapters, I synthesized perspectives from the mathematics and science education literature to construct a framework to guide my analysis. The framework included four dimensions: the nature of statistics, the nature of statistical knowledge, the nature of knowing statistics, and the nature of doing statistics. Of the four dimensions, two—the nature of statistical knowledge and the nature of knowing statistics—stem from work by Hofer and Pintrich (1997) and were also used by Diamond and Stylianides (2017). I include two additional dimensions—the nature of statistics and the nature of doing statistics—to reflect domain-specific considerations in statistics, as reflected in the mathematics and science education literature.

My aim in this section is to unpack domain-specific sub-dimensions that appropriately categorize the participants’ answers within each larger dimension. I draw parallels between my findings and those of Diamond and Stylianides where appropriate, while also proposing differences that seem specific to the GTA population—Diamond and Stylianides interviewed statistics faculty members. Considering that I conducted case studies (rather than Grounded Theory or survey research, for example), I do not present these sub-dimensions as generalizable to or comprehensive for all statistics instructors; rather, they highlight key distinctions and tensions expressed by these four GTAs (Yin, 2009).

The reader may wish to reference Appendix C to see the interview questions posed to participants. In particular, responses to questions in I-3 (and some from I-1) provided the basis for many ideas discussed in this chapter.

The Nature of Statistics

General results. In their statistical epistemology framework, Diamond and Stylianides (2017) explored the justification for knowing, which indirectly relates to the nature and purpose of statistics. In that study, the participants cited data, problem-driven research, intellectual curiosity, and sociocultural motivations as justifications for engagement in statistics. Additionally, Schoenfeld (1992) and Stanic and Kilpatrick (1989) discussed important motivations and purposes for pursuing mathematics: mathematics could be social activity, a means of recreation, a means to solving problems, a pathway into abstraction, or simply practice. The questions these authors ask mirror several of my own considerations.

My primary pursuit, however, involves a more fundamental probing of the nature of statistics. In particular, I examine how the participants defined statistics, what types of problems the participants believed could be answered with statistics, and how statistics might be distinguished from or related to mathematics. I asked questions that targeted several different concepts, including the distinction and purpose of statistics as a discipline, as well as how statistics as a discipline is structured.

Among the identified concepts discussed, I noted the following: interdisciplinary applications, the role of assumptions, the role of proof, the topics of statistical problems, the procedures of statistical problems, and the philosophical roots of statistics. A summary of these concepts is presented in Table 4.1. While some of these concepts were linked closely to interview questions, some emerged from the data (e.g., the topics and procedures of statistical problems). Furthermore, not all GTAs engaged in discussion of each of these topics. For example, only Sahil and Li discussed the philosophical roots of statistics or the role of proofs without prompting. These topics were touched on in questions framed for later dimensions, but Li and Sahil brought in these discussions extemporaneously as they distinguished statistics from other disciplines.

Table 4.1. *Nature of Statistics Concepts*

Concept	Description
Interdisciplinary applications	Ponderings on the useful applications offered by statistics to a wide range of disciplines
The role of assumptions	Noting the types of assumptions needed to apply statistical methods; Discussing the presence of axioms in statistical proofs
The nature of statistical proofs	Discussing the characteristics of proofs in statistics
The topics of statistical problems	Identifying patterns in the types of problems statistics seeks to address
The procedures of statistical problems	Pointing out the specific procedures/methods involved in statistics
The philosophical roots of statistics	Reflecting on the meaning and contribution of statistics as a discipline

All four participants shared some common ground, such as noting that statistics was centrally concerned with data and closely related to mathematics in nature and structure. All participants also mentioned statistics being a process rather than a static set of formulas and methods. All shared similar sentiments about statistics being interdisciplinary as a tool for research in various fields. Differences primarily emerged in the importance that each of these concepts played in each GTA's conception of statistics. In particular, Mindy and Kathy each expounded more when discussing the types of problems statistics can address, while Li and Sahil spent provided more detail when discussing the philosophical roots of statistics and the nature of statistical proofs. I now move to conveying important findings from the data with respect to this dimension.

Cross-case findings. The participants' varying past experiences in statistics and motivations for joining the program provided helpful insights for understanding their perspectives on the nature of statistics. More detailed discussions of these influences are presented in Chapter 5, but summaries of each participants' views are provided in Table 4.2.

Table 4.2. *Summary of the Participants' Views on the Nature of Statistics*

Mindy: Statistics as a Flexible Extension of Mathematics into Context - Statistics is about applying mathematics into context - Statistics is built on assumptions, and methods are appropriate if the assumptions are true; mathematics is more universally true - Statistics typically involves solving more open-ended problems that may not have a right answer or correct procedure to follow - Unsure about the nature of statistical theory	**Li: Mathematics and Statistics Taking Two Diverging Philosophical Approaches** - Statistics is about accounting for error and extracting information from data - Statistics attempts to make generalizable claims from incomplete information; Mathematics starts from assumed truths and constructs a logical system - Statistical proofs focus on making claims of relative confidence, while mathematics aims for absolute claims
Kathy: Statistics as the Process of Applying Mathematics - Statistics is about supporting interdisciplinary research using matheamtical methods; It is an umbrella discipline for application - Statistics follows a mathematical, methodical process to arrive at solutions - Statistical work also involves attention to context, while mathematics is strictly the computation and derivation	**Sahil: Mathematics as the Basis of Statistics** - Statistics is the mathematical approach to making sense of data - At a low level, mathematics and statistics were inherently similar; however, statistical problems required more complex interaction with real-world problems at advanced levels - Enjoyed practical problems, but with preference for understanding why procedures worked

While the participants expressed common ground across several shared concepts, larger distinctions were drawn in each participant's focus and blending of these ideas. A major distinction emerged between the more applied focus offered by Kathy and Mindy versus the more theoretical focus conveyed by Li and Sahil. This applied perspective was characterized by a focus on how to solve problems, while the theoretical perspective was characterized by a focus on understanding statistical mechanisms and conceptual connections. I represent this difference in approach as a spectrum that represents participants' varying focus and familiarity with either the more applied end of statistics or the more theoretical content (Figure 4.1). Additionally, the participants took varying stances in how statistics related to mathematics. I present three models to represent how the participants positioned statistics with respect to mathematics (Figure 4.2).

Figure 4.1. Focus on Applied versus Theoretical Components of Statistics

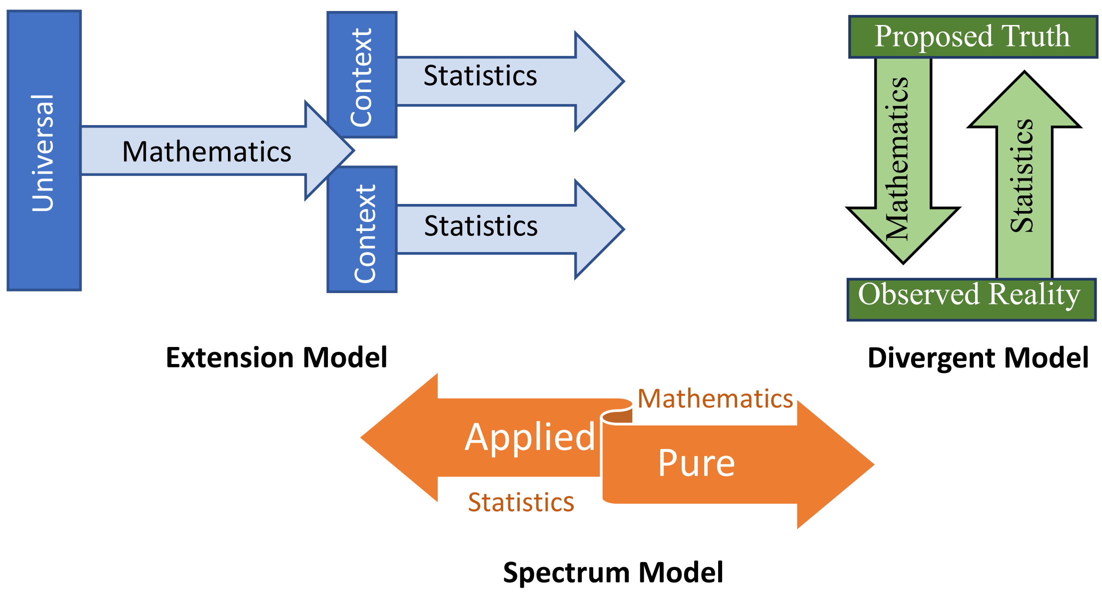

Figure 4.2. Models Relating Statistics to Mathematics

Mindy and Kathy each had summer program/internship experiences that stressed the applied nature of statistics and admitted to not having as much expertise from which to discuss the theoretical nature of statistics. When the topic of proofs and assumptions came up, Mindy and Kathy both acknowledged that statistics involved proving, but each struggled to articulate what that meant. As Mindy stated in I-3: "In math, you're given proofs all the time. I did so many proofs in college, whereas in stats, I've never done a proof. So I'm sure they're important to have, I just have no experience with them." Instead, both Mindy and Kathy focused on the types of problems involving statistics with which they were familiar and their observations that statistical problems were situated in stories or long narratives. Mindy joked that the quick way she might differentiate statistical problems from mathematical problems was by seeing which ones were the "long ones."

Li and Sahil each gravitated toward the theoretical side of statistics, having had coursework that emphasized proofs and the underlying basis of statistical methods. In contrast to Mindy and Kathy, Li and Sahil rarely discussed applied problems in their interviews. They instead discussed the logic structure behind statistics, the influence of mathematics, and the basis by which we can use methodology. Such discussions reflected Sahil's advanced coursework in mathematics and statistics (being the only one of the four with a M.S. in statistics already), as well as Li's extensive reading on statistics and mathematics philosophy.

When I was developing models to represent the participants' respective views about statistics, it made sense to consider these perspectives in light of their discussions of mathematics. The Spectrum model reflects an inherent similarity between the two disciplines, with statistics simply being more concerned with applied problems. Kathy reflected this view as she noted many similarities between statistics and mathematics; she described both as having assumptions and utilizing fixed methods, making them both "hard and fast sciences." To distinguish the two, Kathy said of statistics, "it's not just learning the equation, it's learning how to interpret the equation and what it means, and I think that's just as important as getting the right answer." In this way, mathematics did not necessarily prioritize making sense of situations, but rather completing computation and using formulas correctly. Statistics, in contrast, was more concerned with how computational results allowed for meaning and interpretation.

The Extension model also reflects an inherent similarity in structure between mathematics and statistics, but with the two disciplines making different kinds of claims and contributions. While mathematics makes universal claims, statistics makes more contextual claims. Mindy expressed this perspective by noting that mathematics is more straightforward than statistics and could be described better as an exact science involving certain formulas. She viewed statistics as more situational and assumption-based, explaining that every time you use a particular statistical test, you need to check that assumptions are met first (e.g., random, independent sample). It seemed to Mindy that using mathematics does not require assumptions: rather, mathematical rules (e.g., the distributive property) might better be viewed as universal truths that require no assumptions.

The Divergent model proposes statistics and mathematics as taking diametrically opposed approaches to accomplish a similar purpose. Li most clearly described this model. He explained that statistics rests on the philosophy that we can never figure out the truth. Mathematics tries to prove truth under starting assumptions (e.g., Euclidean Geometry) and attempts to create a comprehensive and logical story. Statistics by nature cannot provide a full story, but simply a reasonable story. He described statistics as starting from the data through observable reality and attempting to reach a reasonable proposition of truth, while mathematics starts from proposed truth and logically proceeds to model reality.

The Nature of Statistical Knowledge

General results. The statisticians interviewed by Diamond and Stylianides' (2017) discussed certain components of statistical knowledge as being objective, constructed, or socio-cultural. My dimension reflects some of these considerations by focusing on the objectivity of statistical formulas, whether statistical knowledge may be viewed as truth, and what role context plays in establishing validity of knowledge. For this dimension, I categorized respondents' discussions into four concepts that largely mirrored the interview questions posed. Table 4.3 provides a brief summary of these concepts.

Table 4.3. *Nature of Statistical Knowledge Concepts*

Concept	Description
The basis of statistical formulas	Reflecting on whether statistical formulas are discovered or constructed, and from what basis and purpose statistical formulas are generated
Contextual influence on methodology	Considering whether/how context may dictate the usefulness of a method or formula
The Goals of statisticians	The perception of statistical ideas proposed in publication and practice as being discoverable truths or constructed ideas
The objectivity of quantitative data	Examining to what extent quantitative data can be trusted and perceived as objective

Before delving into the findings, I quickly highlight one particular line of questioning in this segment. The first question began by asking students to comment on the formula for the sample standard deviation (shown in Figure 4.3). Since measures of spread—and measures of variation with respect to the mean in particular—have been a widely debated topic in the history of the discipline's development (Gorard, 2006), I believed a close analysis of this formula might elicit epistemic views about the nature of statistical formulas. For example, Gorard explains that an alternative measure, the average absolute deviation (i.e., mean deviation), was more common in practice in previous decades, and still has several advantages in particular situations. Probing students views about the validity of such an alternative measure allowed for revealing conversations about the basis for statistical formulas and possibility for open-ended decision-making in the discipline's development.

$$s_x = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

Figure 4.3. Equation for Sample Standard Deviation

Cross-case findings. Short summaries of the participants' views on this dimension are summarized in Table 4.4. The GTAs in this study reflected several interesting lines of thought as they grappled with many epistemic wonderings they had never thought deeply about before. In general, Li and Sahil were more comfortable and talkative than Kathy and Mindy in these phases of the interview. They both expressed open views toward the development and meaning of statistical formulas, while Kathy and Mindy both largely viewed formulas as objective, unquestioned measures—at least until the question was posed to them.

Table 4.4. *Summary of the Participants' Views on the Nature of Statistical Knowledge*

Mindy: Statistical Theories as Objective; Methods and Claims as Contextual and Open - Statistical formulas follow logically from statistical theory and are largely objective measures - Statistics has both discovered and constructed elements, but emphasis on construction when it comes to addressing real-world problems - Statistical claims are prone to error	**Li: Statistical Knoweldge as Subjective and Contextually-Driven** - Statistical formulas are not exactly correct or incorrect, but more or less useful for particular needs - Statistical knowledge is inherently relative based on attempts at reasonable solutions - Statistical claims are subjective and interpretive
Kathy: Statistical Knowledge as a Science that is Fine-Tuned - Statistical formulas are approximations of truth and may be fine-tuned or replaced over time - Statistical theory is invented as we seek truth, but some room for construction and multi-faceted approaches when developing methodology - Statistical knowledge claims are interpretive, but result from objective measures	**Sahil: Statistical Knowledge as Reflecting Objective Core, but Prone to Error** - Statistical formulas represent reasonable measures of particular phenomena, but models are always imperfect - Statistical theory may be thought of as discovered, but methodology is constructed to fit the problem - Statistical claims are somewhat objective, but always prone to random error

In my synthesis of this dimension, I frame the ideas shared along two spectrums. The first spectrum represents the source and interpretation of statistical knowledge from universal to relative. A universal view reflects an inherent truth to statistical theories and method, while a relative view reflects statistical theories and methods as having an interpretive and contextual validity. This spectrum is presented perpendicular to a second spectrum which notes the degree to which statistical knowledge may be viewed as discrete (Schommer, 1990) (i.e., knowledge as right and wrong or unambiguous) versus statistical knowledge as complex (i.e., integrable, nuanced, or clouded by random noise and error). I relate this dimension of the framework as a grid due to the overlapping nature of these spectrums (Figure 4.4).

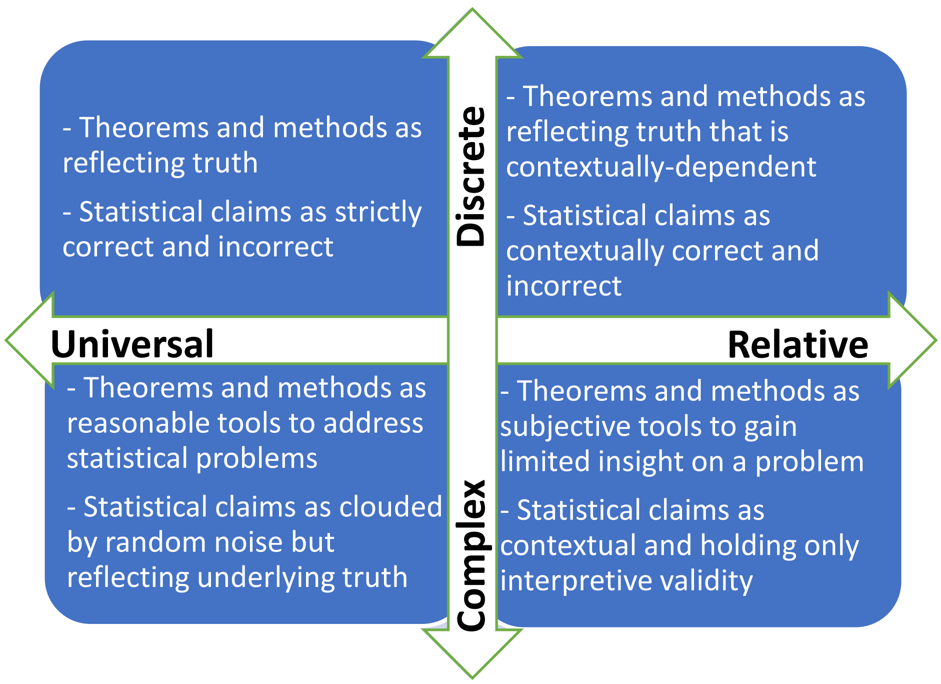

Figure 4.4. Framework for the Nature of Statistical Knowledge

Regarding a universal view toward statistical knowledge, Kathy typically regarded formulas and theory as “building blocks” that were indisputable fact, or “hard and fast science.” She described standard deviation as “the best [formula] we know” for measuring this characteristic, but that there was “always room for improvement.” Sahil also reflected statistical knowledge having an objective core; he described statistics and mathematics being indistinguishable from a theoretical standpoint, and that these theoretical underpinnings reflected a system of logic. However, he did ascribe at least some contextual factor to the validity of a measure. In contrast, more relative and contextual views about the nature of statistical theories and methods came across in Li and Mindy's responses. Li explained that standard deviation added a penalty on more extreme values when measuring variability, while mean absolute deviation did not: the appropriateness of the formula depended on context. Mindy struggled with this tension more than the others, as she initially took a more universal view towards formulas. However, she eventually decided that certain concepts (e.g., variability, center) were fundamental to statistics while the specific measures people might use (e.g., standard deviation, mean absolute deviation, inter-quartile range) held meaning relative to context.

The discreteness and complexity of statistical knowledge is reflected most distinctly in the participants' views toward statistical claims. For example, Sahil and Li frequently expressed rather deep, nuanced views regarding the nature of random error and bias in the process of statistics that clouds the claims that can be reasonably made. Theories and formulas are constructed and do not exactly represent truth, methods are imperfect in their attempts to model real-world problems, data is often biased, and interpretation is individually dependent. Kathy tended to express more discrete views toward statistical knowledge and knowledge claims. She remarked that in statistics (as in mathematics), there is "a process and a right answer," while Mindy likewise reflected that certain fundamental building blocks and equations were the way they were for a reason, or that there was only one way for these components to be. Although, Mindy reflected a more hybrid conception on this matter, as she also expressed that methods and statistical claims were anything but black-and-white.

The Nature of Knowing Statistics

General results. The nature-of-knowing-statistics dimension extends many of the ideas discussed in the previous dimension to the topic of personal and communal certainty and development of disciplinary knowledge. This dimension is closely related to Diamond and Stylianides' (2017) discussion of the attainability of truth and the source of knowledge. In their work, statisticians discussed elements of statistics that could be deemed as "discovered" (e.g., consequences of axioms, questions, and assumptions; solutions to practical problems; and nature of the underlying system) and elements that could be deemed as "constructed" (e.g., data; axioms; assumptions; statistical frameworks; and questions driving statistical work). Diamond and Stylianides also discussed the development of knowledge, including the role of community collaboration and peer negotiation.

For this dimension, I categorized respondents' discussions into three concepts. *Community negotiation* reflects the nature of peer review (as directly addressed in the questioning), while *the role of proof* considers the attainability of truth and certainty in statistical knowledge-building. The third concept, the *cultural influence on disciplinary development*, was a theme I originally considered in the nature of statistical knowledge, but it led to important distinctions in how the participants understood the nature of codifying knowledge and whether cultural factors affected development. These concepts are presented in Table 4.5.

Table 4.5. *Nature of Knowing Statistics Concepts*

Concept	Description
Community negotiation	The nature of peer review in the development of statistical theory and methodology
The Role of proof	The certainty of stated claims in the development of statistical theory and methodology
Cultural influence on disciplinary development	Considering whether/how cultures may influence the kinds of problems the field takes up and how statistical knowledge develops

Cross-case findings. How the participant discussed the certainty of knowledge and nature of developing such knowledge as a community differed depending on whether they were discussing theory or methods. For example, Mindy's focus on methods and application drove her perspective that statistical knowledge required community review and negotiation. Li instead discussed statistical knowledge as having degrees of validity based on community approval. Kathy and Sahil initially focused more on theory and formulas, leading them to think of peer review more as a formality for verification or fine-tuning rather than a necessary step in developing ideas. Summaries are presented in Table 4.6.

Table 4.6. *Summary of the Participants' Views on the Nature of Statistics*

Mindy: Methodology as collectively negotiated and theories as objectively codified	**Li: Statistical Knoweldge as Negotiated to be Reasonable**
- Methods as constructed by and dependent on community for negotiation for validity; theories as verified - The discipline is socio-culturally dependent since it develops according to unique perspectives and mindsets of the people in that culture - Unsure how to discuss nature of proving in statistics, but considered it to be assumption-based and needing to be negotiated by community	- Statistical knowledge given more validity as reviewed and accepted by more of the community - The development of the discipline follows from the complex problems the field is trying to answer, and each culture emphasizes different criteria for validity - Proofs are quasi-mathematical, but context provides meaning. Methods extend as reasonable improvisations from proof
Kathy: Statistical Knowledge as Truth that is Collectively Pursued	**Sahil: Statistical Knowledge as Individually Pursued but Holding Collective Goals**
- Statistical knowledge as verified and fine-tuned by a community - Culture influences the kinds of problems the discipline addresses and how methodology is structured; objective building blocks remain the same - Proving in statistics is the same as in mathematics	- Statistical knowledge as verified and disseminated by a community, but largely developed by individuals - Culture has little influence on the development of the discipline, as there are objective disciplinary norms that all value - Proving in statistics involves testing in more and more cases (e.g., does this method perform better?)

In parsing out the GTAs' views, I again developed two spectrums to reflect the varying perspectives the GTAs were bringing to these questions. The first spectrum reflects the role of the statistical community serving to primarily verify knowledge or negotiate knowledge.

Verification would symbolize knowledge as primarily discovered or constructed by individuals validated through a process of checking. Negotiation symbolizes knowledge going through a process of refinement in peer review. Secondly, knowledge may also be viewed on a spectrum from deterministic to socio-culturally dependent. In the former case, knowledge follows a strict process of development that would be universal in any culture. A more socio-cultural view of development recognizes disciplinary development being dependent on particular culturally-based problems, considerations, and perspectives. In this light, there is no correct or objective way for statistical knowledge to develop. Figure 4.5 presents a diagram of these different thought-processes. These two spectrums are drawn as one-way arrows to emphasize that the left end, Verification and Deterministic, reflect what I consider a starting point for novices. More sophisticated views likewise recognize some level of negotiation in determining knowledge as we understand it (Diamond & Stylianides, 2017; King & Kitchener, 1994).

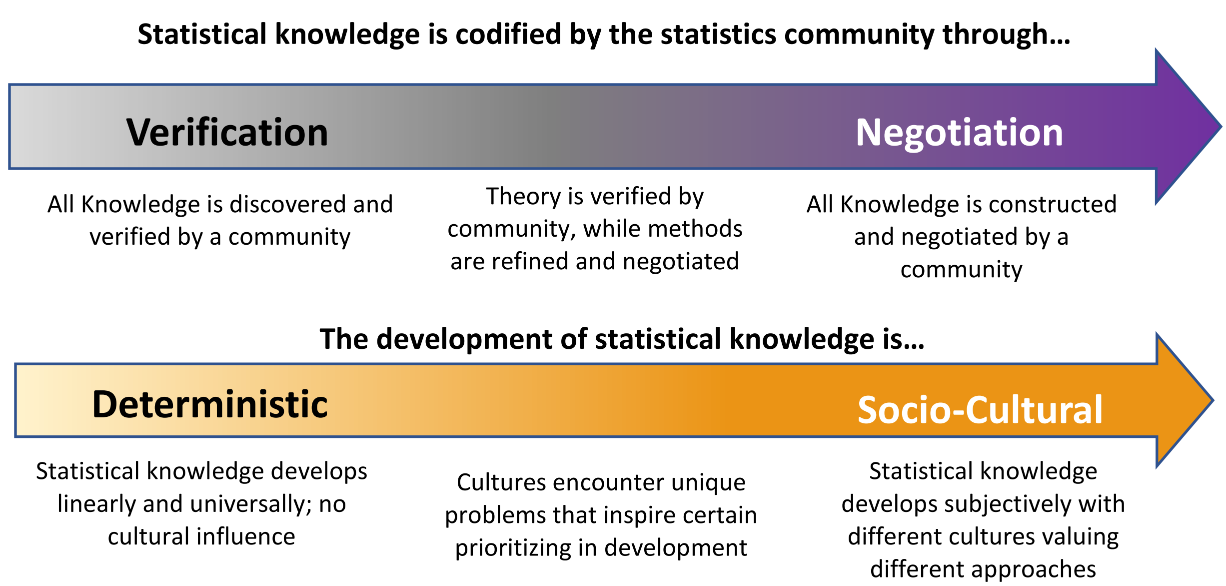

Figure 4.5. Spectrums for the Nature of Knowing Statistics

Mindy reflected the most community-dependent perspective on statistics, which was largely a reflection of her focus on application and interpretation. The validity of a method had to be determined through peer review. Regarding theory, Mindy had less certainty on the matter, but tended to think statistical theories were more of a discovered nature and, thus, merely verified. Sahil likewise reflected Mindy's perspective by holding theory as discovered and verified and methods as more constructed and negotiated. Li held a more consistently negotiated view as he believed that even theories were somewhat subjectively developed and assigned meaning only by their need and contextual value. Kathy took the opposite perspective by expressing statistical theories and methods as essentially proving itself, much like scientific theories becoming laws, and needing only verification by the community.

The purpose and application of statistical knowledge was framed by participants on a spectrum from deterministic to socio-culturally-dependent. Sahil expressed some semblance of a deterministic viewpoint toward methodological development by stating that there were objective underlying principles to developing and using methods, regardless of culture. He stated, "I think the main focus of research is dealing with difficult problems and developing elegant methods, so I believe any good researcher would follow the norms as such." He expanded on this point by explaining that there was uniformity in what the community of statisticians deemed appropriate methodology. Kathy took a more middle-road perspective explaining that different cultures may encounter different problems. Still, there was an objective foundation of building blocks they were drawing from.

The alternative end of the spectrum viewed statistical knowledge and conventions as having multiple valid pathways and being heavily attached to context. From this perspective, Li and Mindy both viewed methodology as developing in response to problems that arose and being quite dependent on who was addressing those problems. Different cultures brought forward different pressing problems and orientations toward meaningful analysis; thus, new methods and approaches were birthed as a result of cultural and community differences. The development of the field did not hinge on following a particular enlightened path, but could reasonably develop along one of many paths.

The Nature of Doing Statistics

General results. The nature-of-doing-statistics dimension probed the participants' views about disciplinary engagement in statistics. Interview questions included topics on what it means to be knowledgeable in statistics, how people may approach statistical problems, and how or whether they might demonstrate individuality in their approach and end-result.

Responses across the participants yielded four relatively consistent concepts of discussion. The first category—the standard for knowledgeability—directly stemmed from the related question as participants grappled with describing what characterized an expert (or novice). A second concept centered on identifying different levels of participation for people in the discipline of statistics. These conversations yielded interesting dialogue about how even students in an introductory course could participate in statistics, providing a nice bridge into the GTAs' pedagogical views later on. The participants also discussed the nature of solving statistical problems, including what kind of knowledge went into this work and how that knowledge mattered. The fourth identified concept was the role for creativity and individuality in the work of statisticians and data scientists. I provide summaries of these concepts in Table 4.7.

Cross-case findings. This dimension was informed closely by Tsai and Liu (2005) and Stanic and Kilpatrick (1989). In particular, Tsai and Liu discussed how participants viewed invention, creativity, and stability as part of the work of science. The participants expressed

Table 4.7. *Nature of Doing Statistics Concepts*

Concept	Description
The standard for knowledgeability	The characteristics of someone who is knowledgeable in statistics
Levels of participation	Different kinds of engagement in the discipline for novices and experts
The nature of solving statistical problems	What it means to "solve" a statistical problem; identifying different types of statistical problems; The objective/subjective nature of solving a statistical problem
Creativity and individual expression	The individuality of one's disciplinary contributions and the possibility for placing a unique signature on one's work

varying perspectives on how creativity or even artistic sense might be involved in statistical work, with some taking a more objective stance toward statistical work and others seeing more room for personal preferences and creative licenses. Table 4.8 outlines many of these key views.

Table 4.8. *Summary of the Participants' Views on the Nature of Doing Statistics*

Mindy: Applying Objective Tools Flexibly	**Li: An Artistic Core Drawing from a Breadth of Knowledge**
- Experts have fundamental knowledge of basic ideas in addition to understanding the full process - From a big picture standpoint, doing statistics is flexible, creative, and open-ended, but there are objective procedures one may draw on - Not artistic, but it does take creativity	- Experts should understand existing methods and are able to create new methods - Statistical problem-solving becomes more flexible and creative as problems grow in complexity - Statistical work, at its core, is artistic as it draws on feelings and life experience
Kathy: Methodology as a Decision Tree with Clear Paths	**Sahil: Individualized Voices among Objective, Tested Methods**
- Experts understand existing methods and have fundamental knowledge of basic ideas - There is a right way to doing statistics much of the time, but there is freedom to choose the method that makes most sense - Individuality is expressed in one's biases and particular methodological preferences	- Experts understand the process of statistics and are familiar with theory - Solving statistical problems sometimes involves using objective methods, but may also require creativity when addressing ill-defined problems - Each statistician may have their own signature and voice in their work

Interesting perspectives and wonderings emerged from the participants regarding the nature of solving statistical problems and the role of creativity. Much of this discussion revolved around what comprised the core of statistical work. For example, Li discussed life experience and artistic inspiration as the core of statistical work. Mindy believed theory was based on objective pieces, but largely viewed statistical problem solving at the higher level as flexible and driven by personal preferences. Kathy shared a more rigid view, explaining that she would classify doing statistics “more as a decision tree rather than a creativity process.” Choices were not exactly flexible; there were simply multiple paths or approaches from which to choose. Sahil took a hybrid of Kathy and Mindy’s views by discussing statisticians drawing on objective methods, but expressing individuality and unique approaches within this acceptable framework for disciplinary engagement.

I present two spectrums that capture various tensions the participants faced when thinking about the work of doing statistics (Figure 4.6). The first spectrum, methodical to flexible, reflects participants’ views about the balance of strictness versus choice involved in conducting statistical work. The second spectrum, knowledge to experience, represents whether participants viewed expertise in terms of pure content knowledge of existing theory and methodology, or as more dependent on personal experience and insight into the context. I again use one-way arrows to emphasize the perspectives reflected on the right-side as resonant with more expert notions toward statistics (Cobb & Moore, 1997; De Veaux & Velleman, 2008; Wild & Pfannkuch, 1999). That said, it is not that methodical or knowledge-based views become irrelevant, but rather insufficient in understanding problem-solving approaches in statistics.

Kathy viewed direct adoption of methods as the primary norm in statistical work. Kathy recognized that statisticians also create new methods, but statistical work for practitioners should

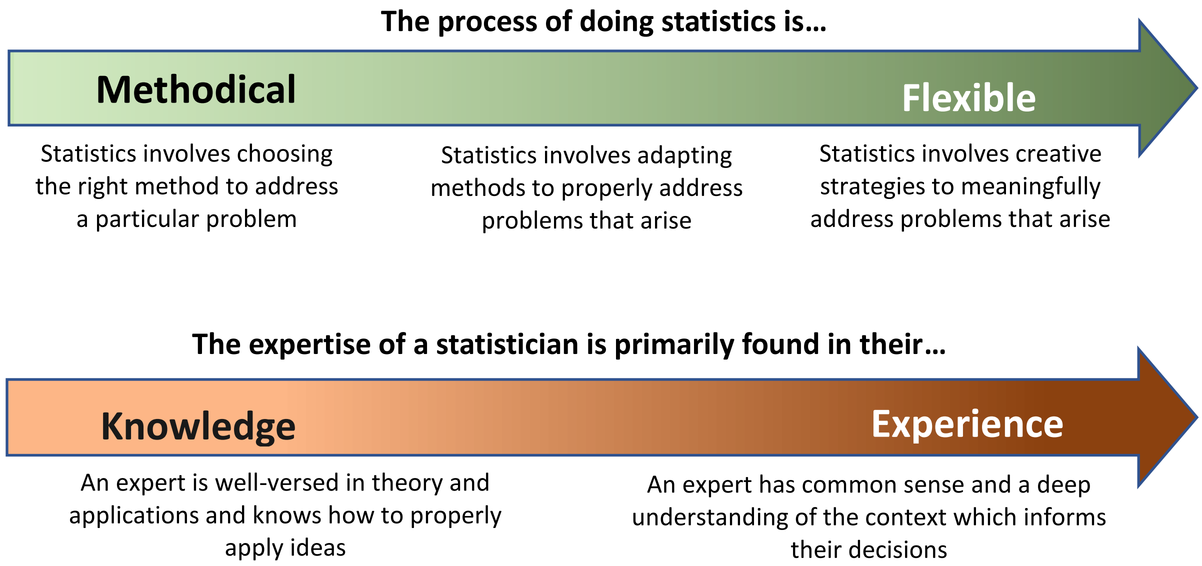

Figure 4.6. Spectrums for the Nature of Doing Statistics

follow existing methods closely. When asked if creativity might play a role in statistical problem-solving, Kathy responded, "I would classify it more as a decision tree rather than a creativity process." For example, she acknowledged that some statisticians follow Bayesian approaches or Frequentist approaches, but that within each of these frames of thinking, there was a process to follow carefully.

Sahil also valued certain methodical elements to statistical problem-solving, as he expressed in his view that all cultures and communities have a shared collection of disciplinary norms guiding their work. He added an additional layer of flexibility, however, by discussing openness in developing new methods and generating theory. He described a disciplinary goal as trying to come up with the most "elegant" methods, not over- or under-fitting, but creating something simple yet robust. He went farther than Kathy in this respect by noting that statisticians utilize a mixture of pre-determined procedures and creative approaches, allowing researchers to add their own impression into their work. Mindy also expressed a flexible perspective. As a volunteer data analyst for a school sports team, Mindy noted that one can use data to simply inform decisions without necessarily needing to run a test. In this way, she viewed tackling applied problems with statistics was quite flexible and dependent on needs.

Regarding what it means to be knowledgeable in statistics, all four participants discussed having strong fundamental content knowledge, such as knowledge of existing tests, knowledge of theory, or knowledge of the process of doing statistics. Sahil discussed knowledge of advanced methods as the true measure of expertise, while Kathy viewed expertise in the ability to carry out correct procedures. Li, however, went farther than the others to also view experience playing an important role. He described doing statistics well as a skill—like playing the piano or drawing calligraphy. Rather than simply applying knowledge, Li viewed doing statistics almost as an art where instinct essentially guides you in the same way that instinct guides a musician in the moment. This instinct might come both from understanding the process of statistics and solving statistical problems many times, or it might also come from deep understanding of the context and the problem itself.

Summary of Disciplinary Tensions

In this section, I presented several models and spectrums of distinction that give insight into the perspectives and tensions that statistics GTAs may express and encounter as first-year graduate students. These models and spectrums are certainly not comprehensive or necessarily representative of all statistics GTAs' views about the discipline, but they do demonstrate a clear finding on the matter: the multitude of views and perspectives that exist. I explore the basis for these differences and the role of experiences on their developing disciplinary perspectives in Chapter 5.

In Figure 4.7, I again present the framework for disciplinary views I have used to guide my study, but with the added dimensional distinctions that emerged from the data. This framework represents a start to understanding the various ways the GTAs organized their views and perspectives. My contributions are limited on this front due to my small sample size; a Grounded Theory approach with a larger group of GTAs and instructors may better serve this purpose. There are likely many more perspectives and spectrums of distinction relevant to this discussion. For this study, however, I use this framework to more richly develop case studies of Mindy, Li, Kathy, and Sahil. In Chapter 6, I unpack their personal disciplinary perspectives and connect these views to their experiences as well as their vision for teaching an introductory statistics course.

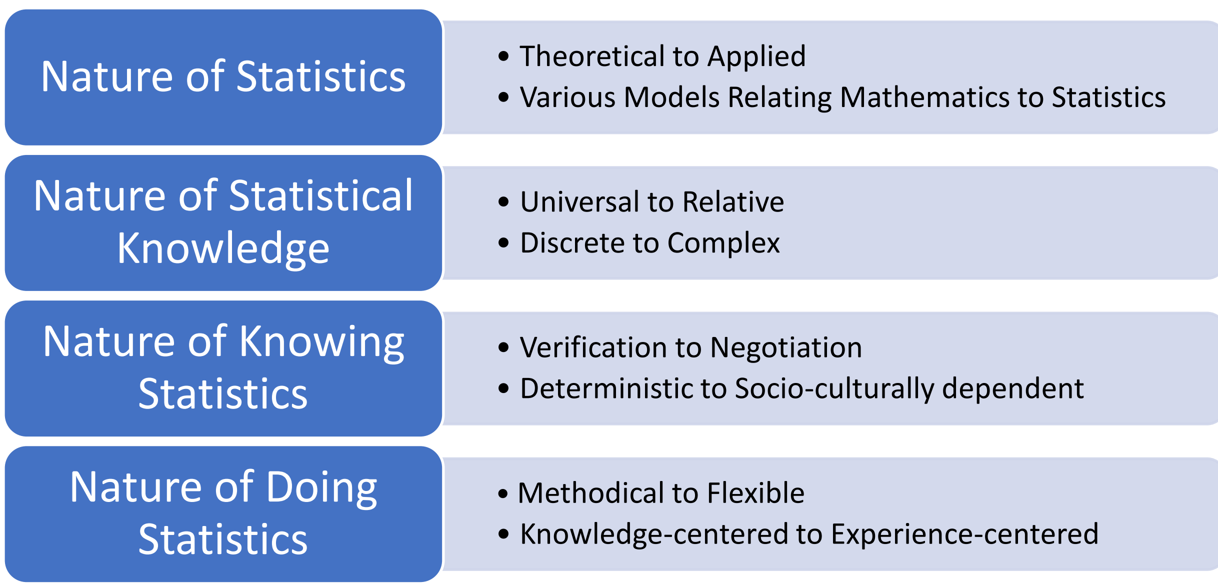

Figure 4.7. Disciplinary Framework with Sub-dimension

CHAPTER 5

CASE NARRATIVES

While the previous chapter focused on cross-cutting themes in the construction of four disciplinary dimensions, this chapter brings more attention to the individuals as I address my second and third research questions. These questions are as follows: "What are the specific disciplinary views of each of these four first-year GTAs? How do their varied experiences relate to their individual disciplinary views? How do their disciplinary views relate to and inform their pedagogical views for an introductory statistics course? What other influences inform their pedagogical views?"

I discuss each participant separately, beginning with a narrative on their background and motivation for studying statistics. I then provide a brief summary of their disciplinary views with reference to the framework outlined in Chapter 4, offering appropriate connections to the experiences and thought-processes supporting these views. Next, I transition to documenting several key findings for each GTA regarding their pedagogical views. These findings also explore important experiences and factors that seem to influence these views, while also considering in what ways these views resonate or counter their disciplinary views. To conclude the chapter, I make conjectures to explain how these GTAs as a group were developing certain orientations toward teaching introductory statistics, drawing together both disciplinary influences as well as other external factors prompting their pedagogical positions.

Mindy

Mindy's background: Data science as a tool for solving interesting problems. Mindy developed a natural affinity for statistics in high school as a member of the math team. "The one subject I did really good [in] was statistics, and I wanted to go to nationals, so I ended up being the best stat person so I could go compete." Taking Advanced Placement (AP) statistics further ignited a desire to choose statistics as her career path. In college, she completed a B.S. degree in mathematics. While her small undergraduate institution offered only one statistics course for mathematics majors, Mindy did have the opportunity to complete a summer internship in data science; she worked extensively in R to create a data anomaly detection program to monitor trends on social media that might identify hotspots for riots or violent outbreaks. Even though Mindy had little experience with R before the internship, she took it in stride: "I read the R for dummies book and went for it!" Mindy set her sights on being a sports analyst. She did recall a short time where she considered becoming a teacher, but she "realized there was so much besides the teaching" (e.g., classroom management) that dissuaded her from that path. She instead liked the idea of solving new and exciting problems every day in the world of data science.

Mindy really appreciated her AP teacher's instructional style: "She did a really good job of showing examples of everything, so we'd learn a topic and go through examples of whatever we just learned, and she made it more applied based." Mindy also appreciated how the instructor incorporated active learning through hands-on activities and a project. Opportunities to work problems in class was another highlight because the teacher would have students come up to the board to complete a problem individually, or with help from classmates.

She had less enthusiasm describing her college mathematics courses, especially her one probability and statistics course. She expressed disappointment in how little they actually did, in part because no professors in her school knew much about probability and statistics:

> Like we didn't have any stats people in my school. Like we had math people, and then we had stats, so these math people were trying to teach stats, but then it was like, it was a mess, we were still going over standard deviation by week 3.

She described that class as “slow-paced” and lacking in much “depth.” Regarding her previous mathematics instructors, Mindy remarked that she “liked the ones that did examples...I liked when they got interaction between the students, and [would] actually hand the students the marker and have you do it on the board.”

In summary, Mindy was most excited about the interesting problems she could tackle with statistical techniques and the flexibility and autonomy she could take in addressing those problems. She responded positively to learning experiences that emphasized applications and provided plenty of opportunity to complete practice problems. She likewise valued statistics instruction that prepared people to solve interesting problems.

Mindy’s disciplinary views. Throughout the study, Mindy expressed uncertainty about many of the theoretical underpinnings to the discipline, and as an M.S. student in Data Science, her coursework focused on more applied matters. Drawing from her internship experiences, Mindy shared a flexible perspective on the validity and development of methodology while believing that the theory undergirding these methods was likely more objective. Her disciplinary views, as categorized by the framework sub-dimensions in Chapter 4, are presented in Table 5.1.

Table 5.1. *Mindy's Disciplinary Views*

Framework Category	Placement
The Nature of Statistics	Primarily **Applied** orientation Statistics as extending mathematics into context **(Extension Model)**
The Nature of Statistical Knowledge	Statistical theories and formulas as **Universal** and statistical methodology and claims as **Relative** Statistical knowledge as **Discrete**
The Nature of Knowing Statistics	Statistical knowledge as **Negotiated** and **Socio-Cultural**
The Nature of Doing Statistics	Statistics as **Flexible** and rather **Knowledge-based**

The nature of statistics: Statistics as flexible extension of mathematics into context. Mindy’s orientation toward statistics came from her very applied experiences with data science.

When discussing her internship experiences with creating an anomaly detection program, she noted how there was no “correct” way to go about creating this program; she was applying ideas that would serve the purpose of the situation. Mindy viewed statistics and mathematics as both being project-based disciplines and noted that each discipline addressed different types of problems. As an example, she mentioned a project she did in Calculus III to find the volume of her school’s pool. For such a problem, there was a correct answer and solution path to follow, while in statistics, there was not always a right answer, but reasonable claims made in response to a problem or question—much like her anomaly detection program.

Mindy described mathematics as an “exact science” in which methods and procedures were objective and universally applicable. She contrasted this with statistics, in which she viewed procedures as contextual and assumption-based. For example, statistical testing only works under certain conditions (e.g., random, independent sample, sufficiently large sample size), whereas mathematical methods do not require assumptions (e.g., addition, the associative property). “I’m sure there’s assumptions behind all the math that you do, but it was never taught that way, whereas in stats, it always that way.” In this way, she reflected the extension model of statistics, where assumptions specified the context in which statistical results were valid.

Regarding more theoretical and philosophical notions, Mindy admitted having little understanding of the principles and theory on which statistics is based. She mentioned probability as being a foundational idea for statistics, but she did not know how to articulate theoretical differences beyond this observation. In Mindy’s coursework, statistical theory was not exactly taught in her undergraduate or masters track. As a result, she was not entirely sure how to compare the theoretical nature of statistics to that of mathematics.

The nature of statistical knowledge: Statistical theories as objective; methods and claims as contextual and open. Up until I-3, Mindy had viewed statistical formulas as rather rigid and unquestioned. In I-3, she began to ponder this point when I asked her about the structure of the standard deviation formula and why we did not use something like mean absolute deviation. She was intrigued at that prospect:

> You're still going to get different answers. It's a whole different formula!...Maybe that's a better way of observing your standard deviation in your data, but I'd be trying to figure out what exactly you're showing with that, since I've never seen that formula before…[3] I've never thought about different ways to calculate it. I've just been told all my life that this is how we do it.

Mindy explicitly referenced her experiences being "told" a certain way to calculate standard deviation. This seemed to be a pivotal moment for Mindy, as she was beginning to parse out a component of statistical knowledge that was objective and another that was more subjective. On the one hand, there were fundamental building blocks (e.g., mean, standard deviation) that reflected an important underlying phenomenon to be measured, but the construction of these building blocks was perhaps up for debate. By considering that mean absolute deviation might possibly be a "better way" to measure variation in one's data, she revealed that her discrete views of statistical knowledge in the context of formulas was open to more complex considerations. She stated that "[statistics] is not an exact science!" and that perhaps there was no right way to measure spread.

This opening of ideas toward a more complex conception came across more clearly as she discussed the nature of statistical methods and claims. This was more clearly conveyed as

[3] The use of ellipses indicate that text is omitted

she considered that in her Time Series class, [there are] like eight ways to make a model!" As a result, statistics in practice was "not an exact science."

This focus on methods and claims also undergirded her more relative and contextually-based perspectives on statistical knowledge. Even though Mindy viewed the basis of statistical methods and formulas as following directly from probability theory, its usefulness and application depended on the problems and assumptions needing to be met in the real world. From this perspective, methodology represented a contextual strategy for making sense of a problem, but with objective rules and building blocks undergirding these strategies. These views existed against the backdrop of two sets of experiences. The first was her experience as a student seeing formulas that were largely unquestioned. The second was her data science internship in which those around her constructed methods to serve the purpose of contextual problems. Despite her lack of knowledge about the basis of statistical formulas, she yielded a certain level of trust to their validity, but with the accompanying knowledge that statistics carried a constructed, contextual purpose.

The nature of knowing statistics: Methodology as collectively negotiated and theory as objectively codified. Mindy believed that community negotiation was necessary to validate statistical knowledge, at least it was in terms of methods and (after her pivotal moment) even equations. For Mindy, collaboration was closely connected to her perception of data scientists working together with other researchers to tackle interdisciplinary problems. People worked together and built on one another's work in this environment. She was slightly more verification-based when it came to theories and proofs. "I can't just make up a proof and be like, aha that's it! It's knowledge now. Other people have to agree on it, and it has to become accepted in the field of stats in order to become knowledge." She described people agreeing with a proof and being accepted, but she did not exactly see underlying statistical ideas being negotiated.

Regarding socio-cultural influences in statistics, Mindy tended to think that such considerations mattered. She again referenced statistics not being a "hard and fast science" and, thus, different communities may make different decisions.

> We like to think of math and science as this hard topic and that it doesn't matter what language you speak in and none of that really matters in this field as much, but I don't think that's true…I think that some of it's discoverable, I think a lot of it's invented, which is why I think it would differ if another country took the lead. Because I think a lot of it is inventable knowledge since we're coming up with it with our own minds, which is why culture varies so much.

The fact that different cultures had, in reality, different norms was evidence that their approaches to analyzing data would reasonably be different and culturally unique.

These discussions were much more challenging for Mindy when it came to the topic of theories and proving. Having little experience and coursework in this area led her to default toward deterministic viewpoints about underlying principles in statistics. As was explored in her views toward the nature of statistics, Mindy had little experience using proofs in her statistics classes. Instead, Mindy's data science background informed her orientation to statistics as applied and negotiated, which resonated with a more constructed view toward disciplinary development. However, she implicitly associated the more theoretical side of statistics to mathematics. In this way, she viewed the development of statistical theory as more objective and logically proceeding, while the development of statistical formulas and methodology was better viewed as constructed and contextual.

The nature of doing statistics: Applying objective tools flexibly. Regarding who could reasonably be involved in conducting statistical work, Mindy shared a vision for participation that could apply to essentially anyone. She drew on her current experience working with the football team, explaining that coaches use data in quite simplified situations to inform their decisions:

> Even at football, [coaches] just find the mean, who is above the mean, the top three, the max. Even if you're just doing those things, you're doing statistics, even though it's just very basic. And half the time you wouldn't even think about that being statistics.

Mindy saw statistics fundamentally as making decisions from data. Applying statistical knowledge could be quite simple and straightforward. For example, she stated that "there's only one way to [find the mean]." More complex methods, on the other hand, reflected more careful constructions from these basic building blocks, and the validity or meaningfulness of these constructions was dependent on the context they were being applied to.

Mindy believed that the nature of solving statistical problems from a big-picture standpoint was quite open-ended, even when using basic applications.

> It takes creativity in designing your experiment, figuring out how you're going to test it, what is best to test, what is best going to give you the answers you're looking for, because there's so many ways to go about it and different data you collect, so that's where the creativity comes in.

She again cited the football example as a case where statistics was applied quite contextually, pointing out that even the choice to record "top three" was based on your needs, or looking at mean versus median. She explained that complex methods involved even more subjectivity since you had even more methods to consider: "Like there's eight different ways to build a model in time series!" She further cited her internship as an experience that helped her see opportunity for choice when doing statistics. Thus, Mindy saw a considerable flexibility to statistical problem-solving that characterized important components of this work.

In contrast, Mindy was careful to clarify the role of theory and assumptions in the application of statistics. While this was an area that she was less familiar with (having no theory-intensive courses required in her Data Science degree program), she did believe that this component of statistics was much more objective. As such, she believed past theory was the basis for certain tried and true methods that should be followed carefully:

> When you're doing analysis, I tend to follow the past. I'm not knowledgeable enough to go and make my own theorems, so I definitely follow what's been done before me and what you learn in the analysis section…you still have to follow guidelines when you're being creative, so that you don't break your assumptions later.

Here, Mindy was channeling her experiences solving statistical problems in her graduate coursework, where there were existing methods she knew she needed to follow properly. In this way, she viewed statistical work as quite knowledge dependent, while she was still aware of (and partially experienced in working with) problems that required more creative approaches and novel solution paths.

Mindy's pedagogical views.

Flexible elements sidelined. Mindy seemed to face a significant curricular tension between the elements of statistics that personally excited her (primarily statistical thinking goals) and the elements she believed introductory students could handle (procedural and computationally-based goals). As I explore in this section, this tension partly stemmed from her experiences as a student and was solidified by her acceptance of the curriculum she witnessed and facilitated in the GTA Coordinator's course.

From the very first interview, Mindy clearly articulated a view that statistics curriculum should revolve around preparing students to apply the ideas they were learning to real-world problems. This perspective on statistics curriculum clearly aligned with her own disciplinary views: she described statistics as having an applied focus, methods as being contextually appropriate rather than universally appropriate, and flexibility in analytical choices. These disciplinary and pedagogical views both seemed rooted in her personal motivation toward studying statistics, as she articulated in I-1: "I [want] to be solving new problems every day, I guess, and found I want to be a sports analyst. [I] found that niche and realized that was a thing I could do." Mindy naturally linked her own personal journey to statistics with that of many of her potential students—hoping that she could help facilitate their path toward applying statistics to their fields of interest. On the survey, she gave especially strong marks for students completing projects in the course, writing statistical reports, learning to use software to explore and analyze data, and identifying statistical questions. Although, it is important to note that she was enthusiastic about goals resonating with statistical literacy and reasoning as well.

From this classroom vision for emphasizing flexible application, Mindy seemed to be disappointed with what students were actually learning in the department's introductory courses. She thought that the traditional curricular elements did not align with the more flexible understanding of statistics students needed. As a future solo instructor, she stated that she wanted to "help them understand why they're doing statistics and not be robots." This was in response to her observation that the departments introductory course tasks seemed rather procedural and required too much recall of memorized responses from a flow chart. She said in I-4: "I don't think they're going to sit there and run a confidence interval or hypothesis test after they leave a stats class. I know we always say, you're going to use it! But in reality, I don't know if they will." She explained that students needed to understand when such things were appropriate and how to interpret results and make decisions.

Mindy's mind map from I-2 (end of fall semester) reveals some competing curricular interests with the perceived constraints of an introductory course (Figure 5.1). She first wrote a list titled, "explaining the field of statistics." She included discussions of population versus sample and descriptive versus inferential as critical designations to guide the forthcoming structure.

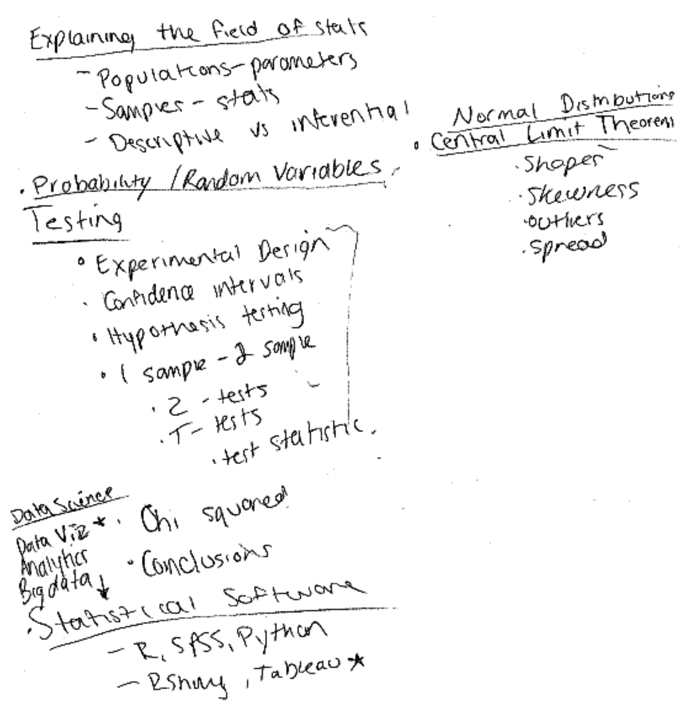

Figure 5.1. Mindy's Mind Map

Her next inclination was to create a "testing" category, but then felt she needed to bridge that gap:

M: And I know I'm missing all the stuff in the middle.

I: What is the stuff in the middle?

M: I don't know, I can't think of it right now…or ok probability, and random variables would definitely need to be here. That was test 3. Central limit theorem and normal distributions. That gets an underline.

Mindy's mind map reflected several key sets of notes that the GTA Coordinator used in her Fundamental Business Statistics course, which included four different sections in her notes titled "Normal Distributions," "The Central Limit Theorem," "Probability," and "Random Variables." In that class, all of these topics were covered before students learned about confidence intervals or hypothesis testing.

Her last category became a catch-all for anything she felt was too advanced for introductory statistics. This category eventually took the name "data science" and included statistical software, visualization, and terms like analytics and big data. It appeared that statistical testing served as the destination to her introductory statistics course vision. Her placement of "data visualization," "analytics," and "software" as external to the introductory curriculum demonstrated her concern for what students could handle in these lower-level courses. Even though she wanted students to experience the more open-ended, conceptual elements of statistics, she shied away from these elements in the curricular elements of her mind map.

Mindy's curricular tension was also demonstrated in I-4 when she sorted different learning goals and course objectives. Table 5.2 shows the summarized results from three different tasks in this interview—the first is her listing of proposed course aims from her own brainstorming. The second is her ranking of nine course objectives. The third is a summary of how she sorted 17 learning goals. There are a number of important placements in these lists.

Through discussions of these lists, I was able to parse which of these highlighted aims, goals, and objectives reflected Mindy's personal preferences versus placement reflecting external

Table 5.2. *Results from Mindy's Course Objectives and Learning Goals Task*

Initial Written Aims	Course Objectives	Learning Goals
Sample vs population (why we take sample and what we can determine about population from them) Distributions – center/shape/spread (normal distributions/Central Limit Theorem) – Need to understand importance of taking larger samples Ethics involved with statistics (she read about this in one of their introductory textbooks) Hypothesis Testing and Confidence Intervals Ability to understand what's said in media Regression (basic ability to make models) Probability/proportions	1) View statistics as a process of designing a study, collecting data, analyzing data, and reporting 2) Be critical consumers of data-based arguments in the media 3) Learn how to use and understand statistical models 4) Awareness of ethical issues 5) Understand basic probability and distribution theory 6) Recognize role of randomness in the statistical design 7) Recognize the omnipresence of variability in the world 8) Link probability to statistical inference 9) Appreciate the mathematics behind statistics	**Not very important** - Elementary coding - Using or interpreting results from a statistical package - Using statistical tables **Moderately important** - Complete problems involving conditional probability - Create visual representations of data - Collect data **Very important** - Complete a full statistical study and write a report - Identify questions that can be answered using statistics - Evaluate study claims from research design - Understand different methods of sampling - Understand Central Limit Theorem - Use calculators for various functions

influences. For example, Mindy valued building regression models, evaluating statistically-based claims in the media, and completing full statistical studies. But amidst these goals were also concerns. For example, Mindy felt it was best to avoid introducing any software in the course because it might be too complicated. She also expressed that certain elements (i.e., sampling methods, normal distributions, the Central Limit Theorem, probability, confidence intervals, hypothesis testing, and regression) that seemed fundamental to the course. Mindy struggled to see how these other more flexible practices and approaches to statistical work might fit into an introductory course.

Students learn by doing. In addition to the influence coming from the GTA Coordinator's notes, Mindy was also drawing on her own experience as a student. Mindy's vision for high-quality instruction was less about solving interesting problems and more about completing a large volume of problems. Mindy believed "students learn by doing"—a philosophy toward teaching enacted by her favorite teachers and instructors. Describing her AP statistics teacher, she explained:

> She did a really good job of showing examples of everything, so we'd learn a topic, and go through examples of whatever we just learned, and she made it more applied-based, which helped me because that's what I was more interested in, so after learning the concepts, [we were] actually seeing how it got applied.

She described introductory statistics as being a "math-based course" and noted that high-quality instruction in both domains involved less lecturing and more opportunities to practice problems inside and outside of class. Even though she distinguished mathematics from statistics as disciplines, she did not seem to make this distinction in the practice of teaching. In both classrooms, high-quality instruction was linked to lots of practice problems and clear connections to application.

Mindy also associated high-quality statistics instruction with the use of helpful problem contexts, but these contexts need not necessarily be interesting or important as much as they be accessible. Mindy recounted that her "biggest takeaway" from the workshop was "including data from class… the kids would enjoy it more, slash they would be a little more involved with it, so it might help to get their attention a little bit better." The experience she was recalling was when the GTA Coordinator had everyone report how many keys they had on them and use that information to create a histogram and find certain summary statistics. Mindy further shared her thoughts on the matter:

> In basic intro courses, we're really trying to apply it, so they understand why they are doing this, why they are learning this basically, trying to make examples that make sense, *like heights of the class*, and things like that

This was a noteworthy divergence from her internship experiences. Mindy now believed her students would be engaged by the nature of the data being collected rather than the questions and problems that emerged from the data. In other words, using data that was accessible and student-centered, rather than posing questions from data that might have significant meaning or allow for important investigation, was characteristic of good teaching.

While Mindy wanted to engage students in problem-solving opportunities, she was unsure how to leverage activities and tasks that would push students to think deeply about the content and make connections between theory and application. Mindy connected her applied perspective of statistics to her view of statistical problems in the classroom, but implicitly reflected a universal view (rather than a contextual view) to the appropriateness and nature of solving classroom problems. In other words, Mindy did not see room for students to reason in context and make decisions about how they might approach an open-ended problem; instead, context was merely the story associated with a problem that added interest.

Li

Li's background: Statistics as a profitable and interesting discipline to learn. Li enjoyed tackling both abstract and applied problems that involved quantitative reasoning. At a personal level, Li recounted that he regularly pondered deep, philosophical questions surrounding statistics as a discipline, regularly expressing his excitement across the interviews for these discussions. With his background in calligraphy and music, musings about statistics as a discipline and its place among other disciplines was an important question for him to grapple with personally. As he stated in his third interview: "I actually think about these questions in my daily life, trying to figure out what is statistics in this semester…every time I encounter some problems, I need to redefine what is statistics."

Li was initially drawn to statistics through his knowledge that statistics was a profitable field to be in. Before beginning his final year in undergraduate school, he decided to take short courses in machine learning during the summer to become more personally familiar with statistics. Additionally, he had undergraduate coursework in mathematical statistics and probability, followed by two computational statistics courses his senior year. However, it was clear that Li was most excited about learning the theory and philosophy undergirding it rather than new applications. Still, Li recognized the profitability of knowing statistics was found in applications.

In his reflections of previous mathematics and statistics instructors, Li painted a fairly positive description. He recalled asking what he perceived as "stupid" questions in class and feeling like "a fool," but finding his professors' responses to be kind and patient as they clearly explained concepts and definitions. The difference he noted between mathematics and statistics classes was the difficulty and nature of the problems they would complete. In mathematics, Li regularly encountered problems that he could never solve, whereas statistics problems always seemed to have a process or algorithm to be used. He partly attributed this to the nature of his statistics instructors, describing them as never wanting to leave questions unresolved, while his mathematics instructors often left them with problems that would never be solved by the end of the course. His initial perception upon entering the graduate program was that statistics coursework is easier and more straightforward than mathematics coursework.

Li's disciplinary views. Among the participants, Li articulated some of the most philosophically deep perspectives regarding the discipline of statistics. More so than any other GTA in the study, he discussed statistical theory and methodology as having a constructed and relative nature. His disciplinary views are presented in Table 5.3, as categorized by the framework from Chapter 4.

Table 5.3. Li's Disciplinary Views by Framework Description

Framework Category	Placement
The Nature of Statistics	Primarily **Theoretical** Orientation Statistics and mathematics modeling reality from different bases **(Divergent Model)**
The Nature of Statistical Knowledge	Statistical knowledge as **Relative** and **Complex**
The Nature of Knowing Statistics	Statistical knowledge development as **Negotiated** and **Socio-cultural**
The Nature of Doing Statistics	Doing statistics as **Flexible** and **Experience-Based**

The nature of statistics: Mathematics and statistics taking two diverging philosophical approaches. In I-3, Li shared a thoughtful distinction between statistics and mathematics; he saw each discipline taking diametrically opposed approaches to the goal of modeling reality.

> A math problem is constructed under some basic assumption, and we try to complete the whole story based on these assumptions. For example, in geometry, we can only draw one line out of, that is parallel to another line…So a math problem will try to prove something under the assumption. It may have no meaning, but they just have to complete this story…[In statistics], we have limited information from the data we observe, we have many latent variables we cannot see and can never see, so we just need to give reasonable

> explanation with these limited samples. And sometimes our explanation sounds reasonable, but is not logical reasonable, but we just need to give the best explanation.

Here, Li is drawing from the analogy that mathematics proceeds "from the top down"; that is, mathematics begins with certain assumed truths and constructs a logical system of truths stemming from those assumptions. He also notes a difference in purpose and motivation between the two: "[Mathematics] may have no meaning, but they just have to complete this story." Li is suggesting that the purpose of mathematics is not necessarily to address real-world problems, but to follow through with curiosities and emerging questions within the system of logic it represents. Statistics works differently by proceeding "from bottom to the top." It is concerned with addressing real-world problems. Statistics makes claims and generalizations based on empirical observation, but it can never reach truth because information is always incomplete. Thus, statistics is built on the premise that we are making reasonable claims based on limited information.

Li tended to focus on the more theoretical nature of statistics, reflecting his familiarity with proof-related problems and personal readings on the purpose and structure of theorems and formulas. Li's tendency to focus on theoretical elements of statistics seemed to reflect his lack of experience grappling with applied problems. He did seem to recognize a paradigmatic difference in the approach of statistics as building methods and conclusions from data, while mathematics built methods and theory from assumed truths. Like Mindy, he saw context playing an important role in the identity of statistics by believing statistics always starts from the data and the problem (bottom up). This had implications on the types of problems each discipline addressed, with both sharing a common aim in attempting to model the world—mathematics from pure, abstract logic and statistics through data-based sense-making.

The nature of statistical knowledge: Statistical knowledge as subjective and contextually driven. When discussing the standard deviation formula, Li demonstrated his deep understanding regarding measures of variability and the meaning behind formulas. In contrast to Mindy, Li was familiar with the use of absolute deviations rather than squared deviations to measure spread, explaining that the former could be meaningful, but the latter included a larger penalty for values that were far away from the mean. He was clear that the basis of the formula was dependent on usefulness:

> When we're working on some problem, our method should be flexible, so we can use absolute value or square value…There is a famous saying in statistics, 'all models are wrong but some of them are useful.' So there is no way to tell the square is better, square is true or absolute value is true. They only way to judge them is which one performs better in some case.

Li reflected both his relative and complex views toward statistical knowledge in this segment. He did not view statistical formulas or methods as right or wrong, but more or less useful in different circumstances. Furthermore, the validity of a measure was relative to the space and context in which it was being used.

This complex and relative view toward statistical knowledge also applied to Li's perceptions of statistical theory. Statistical proofs reflected certain universal principles, but held no truth in a statistical sense. Proofs represented direction, but context still dictated its value for use. Li stated that "[statistics] has its own rules and assumptions" to explain that theoretical underpinnings were developed secondary to methodological needs, rather than methodology logically following from theoretical underpinnings. This perspective aligned with his view that statistics proceeds bottom up rather than top down.

The nature of knowing statistics: Statistical knowledge as negotiated to be reasonable. Li's views about the necessity of collaboration and peer review in knowledge construction largely mirrored Mindy's views. He believed that statistical knowledge was developed in the domain of interdisciplinary problems; thus, statistical knowledge was co-constructed and negotiated by a group of people rather than by individuals. Peer review was a key ingredient in knowledge construction. When asked whether something could be considered statistical knowledge when someone had completed a proof individually, but prior to any peer review, Li responded: "I would say it's statistical knowledge, but it won't be a good statistical knowledge until you publish it." Knowledge, as Li meant it here, was akin to evidence or movement toward understanding of the world. The robustness of knowledge then was strengthened through a process of peer review.

Just as Li differentiated the goals of mathematicians and statisticians, he shared similar sentiments regarding the depths that someone could know and perceive knowledge in each discipline. Since pure mathematics was intended to generate objective knowledge based on large-scale assumptions, the nature of knowing mathematics was more objective: "In math, there is a thing called right or wrong, but in statistics and all other science field, there is nothing called right or wrong—there is just something reasonable and non-reasonable." Li added that reasonableness was judged by how well that contribution was helpful for a given situation.

From Li's perspective, culture absolutely influenced the development of statistics. When contemplating what (if anything) would change if the U.S. were no longer a leader in statistical research, Li hypothesized that China might instead pave the way; in this event, the development of the field would noticeably change:

> The development of this field depend[s] on how complex the problem we're facing. If we didn't encounter more complex problems, our techniques would probably stay the same…I think China has [a] high probability to encounter the cutting-edge problems. So these techniques and theory of statistics will probably develop a lot.

Under this framing, the development of statistical methodology *and* statistical theory follows the nature of problems needing to be addressed. Li viewed the types of problems being addressed as culturally related; thus, the path that the discipline takes would depend on *whose* problems are being encountered.

The nature of doing statistics: An artistic core drawing from a breadth of constructed knowledge. For Li, the nature of solving statistical problems depended greatly on the level of problem being tackled. Like Mindy, Li believed that more complex problems required more creativity and novel approaches: "[knowledge of methods] can just let you know some shorter ways to handle these problems, but it can't help you with everything, so I think statisticians need more creations." A knowledgeable statistician would draw on previous knowledge as much as could be done, but eventually, the statistician would need to make more decisions when no technique perfectly matched the problem being addressed. Previous methods would need to be adapted, and in some cases, new approaches would need to be developed.

Of the four GTAs in this study, Li was most comfortable calling the work of statisticians and data scientists artistic. He related the work of statistics to artistic skills he had had experience with, such as calligraphy and piano.

> Learning a skill is different from learning knowledge. Learning a skill, it doesn't matter if it's painting or learning the piano or whatever it is, it requires someone to feel the pulse of your own body to have the best performance on your work, and the result of your work

> is an art object. So in this case, I think it's kind of statistics, but I won't speak to artists and say, oh what you're doing is statistics.

Through some interchanges of clarification, Li explained that there was a level of freedom and personal creativity in the work of experts in statistics. This work crossed into the realm of art in Li's mind because, at some level, solving statistical problems often involved the individual reaching into their instincts and "soul" to find enlightenment for their work. Thus, Li saw a great deal of flexibility and experience-based decisions in statistical work, with statisticians often crafting new and unique approaches to the problems they encountered.

Li offered a vision for statistics that very much resembles the discussions of leading statisticians (De Veaux & Velleman, 2008) that express something inherently human about this deep disciplinary work. This human element pulls artistic inspiration for approaching statistical problems that cannot be quantified or discovered. These approaches can be unique from expert to expert and draw from a wide-range of "life experience and common sense" (De Veaux & Velleman, p. 2).

Li's pedagogical views.

Curricular views: A conceptual introduction to statistics. When presented in I-1 with three possible aims of the course, representing statistical literacy, thinking, and reasoning, Li moved back and forth between the options. He initially chose literacy, but he also resonated with reasoning: "It's pretty personal; I really want students, everyone to have solid math knowledge and math skills…math teaches students about logic." But Li then conceded that preparing students to be critical evaluators of data-based claims sounded more reasonable an aim for an introductory statistics course.

However, as Li continued to develop his thoughts regarding what non-majors might need in an introductory course, he began to articulate a distinct course vision:

> [Students] really should take some introduction courses to get some basic idea, and in the future when they face this question, though they still don't know how to solve it, they know…that's a question of statistics, and I need some partner who work in this field to solve this problem. Or…I need to gain some knowledge…then I can solve the problem.

In Li's opinion, introductory statistics was not necessarily the course where students should learn how to do considerable statistical analysis themselves. Rather, it was a course that familiarized students with statistical questions, the motivation for doing statistics, and how it could help them in their own field. His curricular view continued to develop on this front; he stated in I-3, "[Students] don't have to understand every detail of statistics, so we can't require them to know every theory. In these cases, showing them how statistics is working is more important." Li was envisioning a course that emphasized a conceptual aspect of statistical thinking by wanting to acquaint students with the process of doing statistics, but without necessarily mastering techniques and methods.

The goal listing and ranking activities from I-4 helped elucidate some of this basic knowledge of statistics that Li envisioned students learning. His responses are presented in Table 5.4. Li discussed several content areas that he associated with a basic knowledge or introduction to statistics and attributed many of these topics to the content in the GTA Coordinator's course that he assisted with:

> For the basic concepts, there are math skills and statistics instruction, which correspond to the same thing in [the GTA Coordinator's course]. And parts about normal

distribution, like random variables and distribution functions, something like this. This will also be included in the first part.

Like Mindy, he also privileged process-oriented goals and ranked projects and components of the investigative process highly in his lists. This aligned with his view that the course was focusing on concepts and presenting to students the idea of statistics. However, much like Mindy, Li was also of the mindset that there were certain fundamental topics and procedures that needed to be included in the course.

Table 5.4. *Results from Li's Course Objectives and Learning Goals Task*

Initial Written Aims	Course Objectives	Learning Goals
Basics: basic math skills, sample, random variable Parameter estimation: Perhaps touch on unbiased estimators or methods of moments if students do well Hypothesis testing: How to design a hypothesis and Type I and II errors Linear regression: Focus on assumptions for linear regression and then the model. Discuss correlation, R^2, and residuals if there is time Idea of statistics. Information about collecting a sample and designing a model; expresses this as a personal desire and interest	1) Awareness of ethical issues 2) View statistics as a process of designing a study, collecting data, analyzing data, and reporting 3) Be critical consumers of data-based arguments in the media 4) Recognize the omnipresence of variability in daily life 5) Understand basic probability and distribution theory 6) Appreciate the mathematics behind statistics 7) Learn how to use and understand statistical models 8) Link probability to statistical inference 9) Recognize role of randomness in statistical design	**Not very important** - Using statistical tables *(not at all important)* - Elementary coding - Learn probability rules, including binomial and conditional situations - Using calculator for various functions - Finding areas under normal curve **Moderately important** - Critique study claims - Develop deep understanding of sampling distributions - Use software to create visual displays, run analysis, and interpret results - Collect data **Very important** - Complete a full statistical study and write a report - Identify questions that can be answered using statistics - Understand different methods of sampling

In reflecting in I-4 on what students might remember from introductory statistics, Li brought some clarity to this tension of balancing traditional problems with a conceptual goal:

> They will forget how to do the Chi square or z or t test, they will forget this, but they will remember there's a hypothesis test…I think the big title will be something that matters in the future. These details are practice to help them have a temporary understanding of this guy. I guess I construct all my course based on the assumption that they are not statistics students. Which means very detailed things won't be important to them in the future.

He envisioned a course in which students were still completing a number of traditional problems and procedures, but as a means to facilitating conceptual understanding.

Li did not take up the mind map task with close connection to introductory level content as Mindy and Kathy did (see Figure 5.2). Instead, he drew many of these terms from his personal studies or his own graduate courses during the past semester (e.g., Python, Machine Learning, High dimension, Clustering, LDA-PCR, and the EM algorithm). When asked whether his mind map resonated at all with the content of an introductory statistics course, Li responded: "The contents of the course are related as a shadow, because the course just introduces basic ideas, so something of probability, and mostly of distribution… It teaches students how to analyze data using histogram or [boxplot]." Here, Li focused on topics that were contained in the introductory course with which he assisted. However, his "shadows" comment painted a picture of introductory statistics content perhaps not emulating the high-level disciplinary ideas he associated with statistics. Truly doing statistics was found in these more advanced methods and theories, while introductory statistics might better be described as learning *about* statistics.

It appeared that Li valued certain conceptual goals and process-perspectives of statistics in an introductory course. At the same time, as a GTA who assisted with this course, Li seemed to be separating his disciplinary views toward higher-level statistical work with the work of introductory students. Li shared a perspective of statistical knowledge as constructed and adaptable, being meaningful only in context, being negotiated and socio-culturally influenced, and involving an artistic sense of creation in the tackling of novel problems. In contrast, Li's

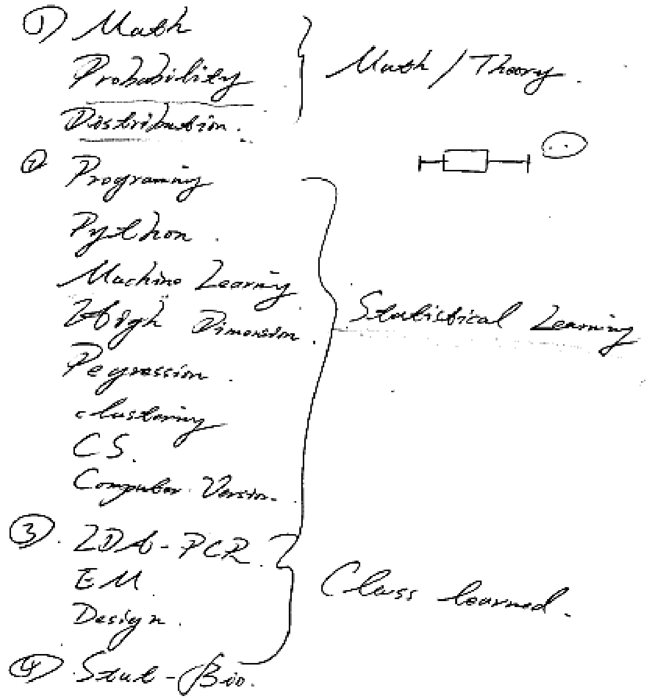

Figure 5.2. Li's Mind Map

curricular views for introductory statistics implicitly reflected an objective canon of content. In this way, introductory statistics was on a different level from higher-level courses, where the purpose was not to engage in the doing of statistics, but to explore scenarios in which statistics could be used and follow known procedures to solving them. It did not seem Li viewed students in introductory statistics perceiving of these more constructed and flexible aspects of disciplinary work; these students had no need to interact with statistics from this perspective.

Instructional tensions: Valuing clarity over messiness. Li frequently brought up instructional clarity across the interviews, explaining that he needed to work on making his "speech more clear and efficient." As a grader for one of the graduate student instructors during his first semester, Li described this instructor's teaching as clear and straightforward. In particular, he was impressed at the close alignment she maintained between her in-class examples/homework problems and quiz/exam questions. When students did not score well on one of the exams in that course, Li cited the issue as knowledge not being effectively delivered in class for that unit. Li also highlighted one of his graduate professors as being a great teacher because his "words were very clear."

Li held to a view of learning as knowledge transfer, where effective teaching was viewed in terms of clarity in lectures and assignment descriptions as well as coherence between the assessed and non-assessed questions in the course. He summarized high-quality statistics instruction in the following statement: "For statistics, to figure out the direction is the strength of the statistics teachers. They can always tell you, we use this formula, or we use this algorithm to do this work, and after that, we can get this output, so that's pretty clear." As a prospective instructor, Li said one of the worst things he could do would be to throw too much information at them at once, explaining that students "miss their way" when the instructor does not keep things streamlined and straightforward.

As a recitation instructor his second semester, Li reflected that he felt bad for often misunderstanding students' questions or misinterpreting something from the activity. He also had little experience using TI-83/84 calculators, compounding communication problems regarding procedures. Additionally, in the teaching workshop, Li was enthusiastic about participating and listening attentively on matters of administration, communication, and respectful relations. In particular, he resonated most with an activity where they read different sample email responses to a student question and discussed which response was most appropriate. From my own perspective of the teaching workshop as an observer, I noted that Li frequently asked questions during workshop segments, especially with regard to policies, proper protocol in various emergency situations, and proper responses to students. "We as TAs, we have to learn how to respond, and some students want to play some tricks. If that happens, we need to deal with the relationship between teacher and students properly to make sure everything is under control."

We had an interesting discussion in I-4 about the possibility of implementing projects in his course. Even though he ranked several goals around the completion of full studies and emphasis on the investigative process highly in the goal ranking tasks, he backed up on this sentiment in our post-task discussion: "I think it will always be helpful to have a student do some research themselves, but for this course, it's all about basic ideas, definition and theorems, basic things about statistics. So I won't think final project will be really helpful." He further explained that this might be something he would revisit in a future semester, "Probably after one year, after I have some experience," but he was worried about the difficulty in implementing projects and his ability to communicate clearly with all of the students about what to do. Li also ranked use of statistical software in the moderately important category in the learning goals task, but again expressed reservations: "For the software part, I don't know how to teach."

Amidst concerns about doing something more complex, like a project, Li did want to find ways to involve students in class and avoid excessive lecturing. Having taken a course in the intensive English studies program spring semester for international GTAs, he was motivated to emulate some of the principles he learned in this course:

> I want to come up with more activities and different ways to introduce this information to them…in [that] course, we are required to prepare a presentation to pretend we are teaching a course, so on that presentation, we need to design activities, try to build an efficient or effective way for students to learn. I think that helps a lot and that makes me think about how to involve students into this course. That's the most important thing.

Li also spoke favorably of the “key activity” from the teaching workshop, just as Mindy did. He saw this as a great way to involve students and build on an experience that non-statistics students could grasp and make sense of. It seemed that having these types of activities modeled for him allowed him to envision administrating these types of tasks in his own classroom. As a result, Li resolved in I-4 to devote a portion of every class period to having students work on a set of problems or complete an activity related to the lecture for the day.

In reviewing Li’s instructional priorities, it appeared that past classroom experiences motivated his privileging of instructional clarity. He noted that his favorite professors were those who made assignments clear and delivered easy-to-understand lectures. As a prospective instructor in the United States, this focus was especially poignant given his lack of confidence in his English-speaking abilities—a concern that he repeatedly raised throughout the study in both the interviews and in casual conversations. He was comfortable facilitating problem-working sessions and even certain student-centered activities, but this comfort ended when potential tasks and assignment bordered on ambiguity. Without clear examples of professors and instructors implementing projects in their course, Li seemed to be dissuaded from trying this for a while, despite his view that students would learn a great deal when interacting with the content in this more holistic manner.

Additionally, it seemed there was some curricular tension between the goals of the course in emphasizing certain foundational terms and ideas and the goals of a statistical project. Li wondered if more traditional, computational problems may instead serve that purpose by acquainting students with the concepts and big ideas this course was comprised of. I attribute some of this tension to a lack of clear vision about what skills and ideas needed to be emphasized. In his written goals for the course in I-4, the category titled “Basics” aligned more closely with these more traditional problems, while the category titled "Idea of statistics" aligned more closely with project-based problems. I posit that Li's focus on instructional clarity led him to raise the goals included in "Basics" above those in "Idea of statistics" due to the more straightforward nature of those goals, as well as close alignment those goals shared with the goals of the GTA Coordinator's course.

Kathy

Kathy's background: Biostatistics as the intersection of skillset and passion.

Having completed a double major in mathematics and human health, Kathy was excited to pursue a Ph.D. in biostatistics. Kathy's path to the discipline seemed to be a matter of logical intersections. She described herself as having always been "good in math," and she later found human health to be something about which she was very passionate. "I'm not here because I love math, I'm here because I want to make an impact in public health, and this could be a means to carry that out." Thus, biostatistics seemed a sensible degree path, with statistics acting as an appropriate toolset to learn for the work of public health. This path to using statistics in public health was reinforced by her experiences taking a graduate level biostatistics course at a summer institute program, where she learned about using generalized linear models and ANOVA to study Alzheimer's disease medicine. Regarding career trajectory, Kathy expressed interest in working in research in the medical field, with the possibility of becoming a professor in time.

Kathy had less than favorable experiences with her undergraduate mathematics instructors. She described these courses as being predominately lecture and exam-based. Kathy described interactions with her professors that left her feeling she "wasn't smart enough" in their eyes. For the most part, it seemed these interactions motivated her to prove herself; Kathy had confidence in her mathematical capabilities and was determined to do well. Her desires to potentially teach one day were linked to her beliefs that she could connect with and encourage her students more than her own mathematics instructors did:

> From my experience, a lot of my undergraduate math professors have been really un-approachable and have just seemed really intelligent and out of reach. So I kinda want to be the opposite of that, just be really approachable and give my students a sense of "hey, she's pretty normal, she can do this, I can do this too.

Kathy saw her demeanor as more down-to-earth, feeling she might encourage students who struggled or simply felt out of place.

As an undergraduate student, Kathy was able to exemplify some of these instructor attributes as a teaching assistant for a freshman-level Health class. The supervisor encouraged each of the teaching assistants to promote discussion and to let students truly bring in their own experiences to make sense of the content. She described her style as approachable, and she enjoyed the format of the class. However, she made comments, however, which I will unpack in the upcoming sections, that the format of her statistics course would not and could not be similar due to the nature of the content of the course.

Kathy's disciplinary views. Of the four participants, Kathy most consistently reflected objectivist perspectives toward statistics. Like Mindy, she had more experience and awareness of the applied aspects of the field, but she did not see the field's development or application as flexible or constructed to the same degree that Mindy and Li did. She did, however, become more open toward more constructivist perspectives on disciplinary development in later interviews. Specifically, in I-3, she became more sympathetic to the aspects of statistics that were contextual and even socio-cultural. Her views are categorically presented in Table 5.5 using the framework definitions of Chapter 4.

Table 5.5. *Kathy's Disciplinary Views by Framework Description*

Framework Category	Placement
The Nature of Statistics	Primarily **Applied** Orientation Statistics as more applied and mathematics as more pure **(Spectrum Model)**
The Nature of Statistical Knowledge	Statistical knowledge as mostly **Universal**, but statistical tests being **Contextual** Statistical Knowledge as **Discrete**
The Nature of Knowing Statistics	Statistical Knowledge as **Verified** and **Socio-Cultural**
The Nature of Doing Statistics	Statistics as **Methodical** and **Knowledge-based**

The nature of statistics: Statistics as the process of applying mathematics. Kathy's description of statistics reflected a methodical process that closely resembled mathematics. She identified several commonalities to both mathematics and statistics, stating that each involve making assumptions, utilizing fixed methods, and being "hard and fast sciences," which contrasted from Mindy's careful juxtaposition that only mathematics was an "exact science." Kathy's perceived alignment between the two disciplines was further elucidated when she compared statistics to human health: "[Statistics] is more math-based, and there is a process, and there is a right answer; as opposed to health, it's how can we apply this information to ourselves." Here, Kathy talked about statistics (and mathematics) as being centered around rather objective procedures and topics, while health as a discipline centered on more individualized and relative truths.

When asked about distinctions between mathematics and statistics, Kathy explained that statistics also involves thinking about the purpose certain formulas serve and knowing when to use them: "[statistics is] not just learning the equation, it's learning how to interpret the equation and what it means, and I think that's just as important as getting the right answer." However, further probing revealed that "interpretation" to Kathy simply meant having a context, but not necessarily reasoning within context or adapting methodology to the context.

When Kathy discussed her experiences in statistics, it became clear that she had had few experiences to work through applied problems outside of her biostatistics summer course. In the biostatistics course, she applied general linear models and ANOVA models, but with a seemingly procedural focus. With mathematical statistics as her benchmark statistics course—taught by a mathematics professor—she expressed the view that, at an advanced level, both mathematics and statistics are based in Calculus. In summary, she largely associated statistics with more applied topics involving data and mathematics with more pure computation and abstract topics. She also believed that both mathematics and statistics were linked foundationally with little difference outside of the problems each discipline seemed to focus on.

The nature of statistical knowledge: Statistical knowledge as a science that is fine-tuned. Like Mindy, Kathy was not familiar with using mean absolute deviation as an alternative measure of variability besides the standard deviation. When I asked her about the traditional formula for sample standard deviation, she responded: "I'm sure it's because a bunch of super smart people back in the day decided this was the right way to do it. I know that's a terrible explanation, but I kind of just accepted it for how it is." While she initially described squared deviations as the "right way to do it," she did open up on the topic to suggest that maybe they were two different approaches toward unpacking a central truth:

> I'm sure there's disagreement, there's disagreement about everything! I think if [the formula for standard deviation] were the universal standard, no arguments, then there wouldn't be a push to find other methods that could be better. I think one of the reasons why stats in particular—but science as a whole—is advancing is because there's always this underlying belief that what we have is good, but it's not the be all end all. I'd be

> surprised if everyone took [the standard deviation formula] as the gold standard, something that could never be beat.

Kathy viewed statistical formulas then as attempts to model objective phenomena, with changes being made for the sake of coming closer to the actual phenomena. Such choices were not necessarily the comparison of contextual needs in the same way that Gorard (2006) discusses, but as approximations to truth. Thus, different choices in using a statistical formula were not relative choices as much as they reflected disagreements about which was universally better.

As seen in the earlier conversation about how the discipline of statistics relates to that of human health, Kathy seemed to see statistical knowledge as discrete and unambiguous. She described the topics of a health class (e.g., sleep) being ideas that students constructed their own ideas around in order to further practical habits. For Kathy, such notions seemed silly to do in statistics: "For [statistics], how do you feel about correlation? where do you see correlation? [chuckling]…It's just not as discussion-based." From Kathy's perspective, statistical content existed independent of students' experiences and could not feasibly be approached in a similar manner as a subject like human health.

Toward the end of I-3, Kathy did open up somewhat to the idea that statistical knowledge was not entirely universal:

> For different sets of variables, there are multiple tests you can use that will tell you different answers, and they've all been constructed differently. Whereas, with math, one example that proves out, 2+2, obviously it's 4. We didn't construct tools to make it that way, it's just accepted kind of as a rule, it's just what it is.

Here, mathematics was seemingly universal, but statistics may have some leeway depending on which test you choose to use. This constructed perspective only went as far as choosing a method rather than the nature of the method or the formula. Kathy described these measures themselves as unquestionable, fundamental building blocks. Thus, her views toward statistical knowledge were marginally relative, but largely universal.

In making sense of Kathy's views, it would appear she had never had a reason to question a statistical formula. Her coursework experience, both in her summer biostatistics course and in her mathematical statistics course, emphasized her perspective that statistical formulas and methodologies were objective and straightforward. Without any opportunity to engage in statistical decision-making where attention to context was key, Kathy implicitly accepted that statistical concepts reflected truths.

The nature of knowing statistics: Statistical knowledge as truth that is collectively pursued. When it came to the role of a community to develop statistical theory and methodology, Kathy was more uncertain on the matter. She leaned toward viewing statistical theory and methodology as something discovered rather than mutually constructed, meaning that peer review was more a formality for codifying knowledge or a means to facilitating discovery, rather than a medium for negotiating knowledge. She stated, "I think once you discover it, it immediately becomes a tool that other people can use to make things better." Collaborators could assist in the elucidation of knowledge, but individuals could still discover and develop knowledge. A follow-up question revealed that she viewed statistics to be equivalent to mathematics on this front:

> I: Some claim that statistical knowledge is discoverable truth, and others would argue that statistical knowledge is invented or constructed by our minds. What's your opinion? How do you think about it?
>
> K: I think we invent it to be able to discover truths.

I: Ok. Alright, so like, it might be insightful to ask the same thing about math. When you think about mathematics, do you think about it as discoverable truth, or do you think of mathematics as something we invent or construct?

K: [long pause] I think we invent it to answer, to come to truths about like, things that we have at hand. I really don't see the two things being separate… Cause I think in order for us to invent these things, there has to be a truth that, we're trying to discover, we have to be working toward something.

In this interchange, Kathy explained that mathematics and statistics fundamentally reflected the same basis for knowledge. In this way, both fields depended on the discovery of ideas, and the community existed to verify these discoveries.

Regarding the influence of culture on the development and practice of statistics, Kathy initially explained that statistics was a hard and fast science where methodology is the same regardless where you are from. Further questions began to push Kathy's reasoning in a new direction. She was next asked to consider what would happen to the development of the discipline if the United States and other Western countries simply left the picture in terms of the development of new research in statistical methodology and theory. This cultural perspective offered a space to then reflect on two somewhat contradictory statements she made earlier in the interview:

I: Like when you say statistics is a 'hard and fast science,' can you say a little bit about that statement, and the statement of, 'science is always changing,' and how do those work together?

K: Sure. So, we have kind of core concepts of statistics or generally agreed upon formulas that, so those are kind of the backbone, but we can use that and take it in a lot of

> different directions to develop more complex algorithms or ways of thinking like that. So what I'm saying about that, if the central basis of statistics shifted from the United States to more of an Eastern nation, then we'd still have more of those building blocks, but kind of the developments we made with those ways of thinking would be different.

Here, Kathy offered a glimpse at a socio-cultural perspective to the development of the discipline. Rather than view statistical knowledge as developing along a set path, she recognized disciplinary development as having the potential to take many paths. Still, there was an objective foundation of formulas from which new complex methodology could arise.

In summary, Kathy believed that knowing in statistics was somewhat objective from the perspective of proving underlying theory. This objectivity became slightly more subjective in the realm of methodology, where she perceived formulas as approximations of truth, but she also believed that different cultures might develop the discipline differently as they constructed meaningful methodologies. Applying methodology could also involve some manner of choice as one had to decide which test might be most appropriate for a given situation.

The nature of doing statistics: Methodological choice as a decision tree with clear paths. Throughout the interview, Kathy described participation in statistics as involving close attention to procedures and details. Pulling from the statistical analyses she completed in her biostatistics program, she closely equated such types of work with running experiments and following procedures. Kathy also used very objective, mathematical language to describe the process of doing statistics, such as "using formulas," "manipulating," "computing," and "finding the right answer." This description closely reflected her classroom experience, both as a student and as a GTA. As articulated in her comparison of statistics and health courses, Kathy said of statistical problems, "there is a process, and there is a right answer." In other words, the types of problems addressed in her classroom experience requested more objective, computationally-based responses.

When Kathy was asked whether solving statistical problems was an objective or subjective process, she responded:

> I think the equation itself is objective, because you have the data, you perform whatever sort of calculation, but I think the way you apply it would be subjective…I think you have to follow the different pre-known procedures definitely. But I think there are different procedures that you can follow for each test, so that's where you get a little bit of individuality.

Here, Kathy identified a component of statistical work that was objective/methodical and another component that was more flexible. This more flexible piece stemmed from the choice that one would make when deciding which set of procedures to follow. Kathy recognized that there was not always simply one method to follow that made sense. This flexibility in choosing a method was associated with more sophisticated statistical problems, but she clarified that statistical work is largely found in careful use of existing methodology.

On the topic of whether there was an art to doing statistics, Kathy replied:

> I think that's a pretty liberal use of the word art…I think statistics is more practically based, and there is more creativity, but I know just from a biological perspective, when you break it down, different sides of the brain, left brain, right brain, whichever one is art, whichever one is reasoning, that I am particularly reasoning brain focused. I'm a terrible painter, terrible artist, but I'm good at statistics, so I think that in terms of art and reasoning, it definitely is more reasoning than it is of art.

In contrast to Li's use of his own artistic experience, Kathy actually drew on her lack of artistic experience and excellence to claim that statistics must not be an artistically-based work. Kathy instead viewed statistical work as more strictly a "reasoning side of the brain" activity, where artistic expression was largely unnecessary. Thus, Kathy clearly saw statistical work as more knowledge- and content-based. When I pressed her more on the topic she did view experience offering some mode of individuality and difference in approach in statistical work. She explained: "Whether they ascribe to be frequentist or Bayesian, either one of those thoughts influence what they do…but I think I would classify it more as a decision tree rather than a creativity process." In other words, individuality would affect what method or approach one would use to addressing a statistical problem, yet, there was still a strict and methodical process to follow within each school of thought.

Kathy's pedagogical views.

Curricular views: A procedural interaction with statistics. Kathy's curricular vision for introductory statistics reflected close alignment with her more objectivist stance toward the basis of statistical formulas and methodology. She viewed statistics, especially an introductory course, as acquainting students with "the basics," which were largely composed of learning about and using various formulas and procedures. At the same time, Kathy was frequently excited about other broad, potential goals for introductory statistics. In I-1, when Kathy was asked to rank the three general aims (statistical literacy, thinking, and reasoning) for introductory students, she spoke highly of each one and argued that all worked together in the course. Her responses on the first survey provides further evidence that Kathy respected goals across all three of these aims. Table 5.6 presents several of these survey items, where a response of 1 denotes strong disagreement and a response of 5 denotes strong agreement.

Table 5.6. *A Selection of Kathy's First Survey Results*

Statistical Literacy	Response
Students should learn to carefully judge and evaluate data-based arguments and claims they see in the media.	5
Statistical Thinking	
Students should learn how to outline a statistical study, including a plan for data collection and analysis.	5
Students should learn how to write up a report describing a study from start to finish.	5
Students should complete a statistical project in the course.	4
Statistical Reasoning	
Students should develop a deep understanding of sampling distributions.	5
The course should spend at least one class period covering rules of probability (like the multiplication rule, conditional probability formula, or adding disjoint events).	4
The course should require students to frequently calculate using formulas (by hand or with calculator).	5
Students do **not** need to learn the mathematics behind statistical methods as long as they can use the methods properly and interpret results correctly.	1

Considering the breadth of topics and goals that received strong agreement from Kathy, in addition to the comments from the interviews supporting many of these goals, it appeared Kathy hoped to accomplish a lot of things in an introductory course. Through later tasks and questions across the study, however, it became clear that the aims of statistical literacy, thinking, and reasoning did not hold an inherent importance. What resulted were, at times, conflicting views about the introductory statistics curriculum.

Important insights about these curricular tensions emerged in I-4 when Kathy had to rank different goals (Table 5.7). On the topic of statistical literacy, one notable inconsistency was Kathy's listing of "judge merit of statistically-based arguments in research/media" first among her personal goals, yet she ranked a nearly identical statement 8 out of 9 on the course objectives task. Even though this was the first thing that came up on her own, she seemed to have changed her mind drastically about its importance when reading the other potential objectives provided:

> So my train of thought was that the [objectives] that deal with the actual methods of statistics are important, and then so in my mind, [critical consumers and awareness of ethical issues] were really the higher order thinking ones.

Here, she referred to it as a higher-order goal that students would achieve after learning the basics. So in this sense, perhaps an introductory course may not get that far, even though she wanted students to learn this. But more confusion came on this front in the learning goals task, where she ranked "students should learn to critique and evaluate a study's claim based on the research design" in the most important category. It seemed that the strict hierarchical ranking made it difficult for her to see this idea as among the most important, even though she still clearly valued this learning goal for students when she merely had to sort ideas in three categories.

She also gave conflicting rankings regarding some of the goals related to statistical thinking. In I-1, she explained that she viewed statistics as a process of research that involves several important components. Furthermore, she listed the process-related objective number one among the nine course objectives. Yet she ranked several learning goals associated with this process-oriented view as only moderately important. She explained that moderately important designation here:

> "Students should complete a full study" and "students should collect data to analyze"—I think these are along the same page, and I think would really be a good end goal for a course. But I maintain that you can't analyze data and do a full study if you haven't learned the basic procedures first.

Here, we see a fundamentally important goal emerging from Kathy's curricular vision: students' understanding of basic procedures. Many of her highest-ranked goals involved completing tasks by hand (with calculator- or software-assisted goals falling in the lower categories). She

Table 5.7. *Results from Kathy's Course Objectives and Learning Goals Task*

Initial Written Aims	Course Objectives	Learning Goals
Judge merit of statistically based arguments in research/media Calculate and understand measures of data (mean, median, standard deviation, etc.) Understanding theorems, especially the Central Limit Theorem Perform and analyze various simple statistical procedures, such as the t-test, z-test, and chi-square test	1) View statistics as a process of designing a study, collecting data, analyzing data, and reporting 2) Learn how to use and understand statistical models 3) Recognize role of randomness in statistical design 4) Understand basic probability and distribution theory 5) Link probability to statistical inference 6) Appreciate the mathematics behind statistics 7) Recognize the omnipresence of variability in daily life 8) Be critical consumers of data-based arguments in the media 9) Awareness of ethical issues	**Not very important** - Elementary coding - Write a full statistical report - Complete a project - Use software to create visual display and interpret results **Moderately important** - Using calculator for various functions - Understand the process of statistics - Use software to run analysis - Collect data **Very important** - Complete tests by hand using statistical tables - Critique study claims - Finding areas under normal curve - Identify questions that can be answered using statistics - Learn probability rules, including binomial and conditional situations - Develop deep understanding of sampling distributions - Understand different methods of sampling

explained that completing work by hand would help students understand the process better and think about their calculations: "If you plug it into a calculator, you don't have to think about it." It appeared that Kathy most highly valued students understanding the computational mechanisms of the content they were learning, with interpretive components being more advanced.

We see some evidence of this conflicted structure in her mind map from I-2 (Figure 5.3). Kathy began with "basics," and explained: "[The basics] are important to know, but they can't really lead you to any results by themselves." She then moved to the next box, using an arrow and the label "why?" to shed light on the motivation for learning the basics. She listed hypothesis testing and its relatives as the landing point. She also listed theoretical support pieces for hypothesis testing (listed across two bubbles) and concluded with a bubble for more advanced items. These more advanced items—chi-square, mixed generalized linear models, regression, and computing—were all methods that she viewed as going beyond an introductory course.

Figure 5.3. Kathy's Mind Map

Structurally, Mindy and Kathy had similar mind maps; however, Kathy's description of each point reflected a more objective, procedural, and methodical view toward the work and development of statistics. For example, she explained that the basics bubble comes first for introductory students because it is "just making sure you have the skills necessary to move forward and go to [Hypothesis testing]." Furthermore, Kathy's advanced bubble reflected more specific procedures and tests, while Mindy emphasized broader themes like, "data science," "visualization," and "analytics." These nuanced differences reflected Mindy's view of students learning statistical practices as they grew more advanced, while Kathy thought of the discipline as progressing in terms of methods rather than concepts and practices.

In connecting her mind map to her views from the interviews, it seems Kathy was drawing most deeply from the topics she encountered in her coursework, as well as the course with which she assisted. At the top of her mind map, she explicitly referenced the course name and code (Survey class, STA1220) to explain this was the inspiration for much of what she wrote down. She also adopted the language of "we" from as early as I-2 to reflect that the department's curricular choices were a basis for her deciding what should be included in these courses. Without vibrant experiences analyzing data outside of the classroom (as Mindy had) or experience personally reading, studying, and exploring statistics (as Li had), Kathy was left with an incoherent vision for introductory statistics curriculum that was constrained to the disciplinary authorities around her. I believe this explains why she would often respond enthusiastically to certain survey items or potential goals and objectives I presented; I was likely perceived as a disciplinary authority as well where my implied curricular suggestions were taken as important. However, these goals were not rooted in a clear, personal vision for the course.

While Kathy reflected some contextual influence in the development of statistical knowledge, as well as personal decision-making in the doing of statistics, these ideas held no place in her curricular vision. She did not discuss the role of context in problem-solving for introductory statistics. Instead, she emphasized students learning the "basics," which included summary statistics, probability, and the procedures involved in rejecting or failing to reject a hypothesis test. However, she expressed no vision for students encountering problems that may not have a defined solution path or correct answer.

Guiding students toward mastery of procedures. While Kathy's curricular views seemed to align with the curriculum she had observed and experienced herself, her instructional views sharply countered those of her previous professors'. As discussed in her background section, Kathy often felt her professors were not always patient and understanding, and she wanted to be the "exact opposite" of that. She presented a vision for instruction where she was seen as approachable and always ready to help her students.

In many ways, Kathy mirrored many of the same instructional priorities that Li expressed. They both spoke highly of the same department professor for similar reasons; Kathy stated: "[He] was my favorite professor, because he was really clear, easy to talk to, [and] expectations were clear." Where Kathy differed slightly from Li was her more emphasized focus on having students learn their basic procedures and find correct answers, while Li saw procedures simply as a means to ensuring conceptual understanding. Thus, instructional clarity for Kathy was associated with helping students through procedures, While Li's was associated with helping see how statistics could help them answer real-world questions. Kathy stated:

> It is important to know the formula behind it, and I don't think you can really understand statistics if you don't understand the formulas and understand why you're calculating what you are, but…it is not as important as arriving at the correct answer and the end game of probability: do we accept or reject this.

While Kathy did value some semblance of statistical reasoning (as seen in her curricular views), it was guiding students to "correct answers" that characterized her instructional strategy.

An interesting point of discussion across Kathy's interviews was how her vision for the statistics classroom differed from that of the Health class she led as an undergraduate TA. While her health class took the form of group discussion generated from guiding questions, her vision for statistics was founded on encouraging collaborative effort on more closed-form questions.

> In the health class, one of the things you might discuss was "how you can better improve your time management by looking at a log filled out for a week." So pretty individualized, whereas [statistics] would be everyone's working together to get the answer, kinda walking through step by step, making sure they all get it.

As documented in her disciplinary views, Kathy also described health as a topic in which students can bring in their own ideas and experiences to guide discussion, whereas she joked at the prospect of doing so in statistics with a topic like correlation. She remarked: "Being a stats TA doesn't require you to be as engaged with your students…when you get the material out, it's not as important to get student feedback immediately, except for just asking if they have questions."

In considering all of Kathy's responses, it appears that her disciplinary views and pedagogical views supported one another coherently. Kathy's discrete views of statistical content motivated her desire to promote group work, viewing her role as a facilitator of students' unified movement toward learning proper procedures and finding correct answers. This instructional vision aligned with Kathy's view of statistical formulas and procedures being universally valid rather than relatively and contextually appropriate. Creativity and personal decision-making was not an element in the course, consistent with her description of doing statistics more as a decision tree than a creative process. Additionally, her instructional vision involved an abundance of practice problems that emphasized mastery of fundamental disciplinary components. Rather than explore open-ended problems with contexts that were relevant to solving, Kathy wanted students to focus on the skeleton of the discipline. With this alignment between disciplinary and pedagogical views, Kathy expressed little dissatisfaction or clear tension in her instructional vision for statistics in the same way that Mindy and Li did.

Sahil

Sahil's background: Statistics as a fascinating area of study. Having completed both a B.S. and M.S. in statistics from India, Sahil reported having had extensive course background in theoretical statistical topics as well as mathematics. He recalled having very little content focused on applications. For example, his program used the C programming language (generally a more mathematical language) exclusively rather than R (a statistical language). He entered the Ph.D. program with thoughts of being a statistics professor and doing research.

Sahil first took an interest in statistics in high school. He remarked that he was always good at mathematics; statistics stood out to him then as being mathematics, with the difference being its more exclusive focus on applications. Still, even the applications he was learning in high school and college were heavily embedded in theoretical content first. It was not until he was working on his M.S. degree that he began to learn R.

Sahil's statistics instructors tended to be lecture-focused with little to no opportunities for students to talk: "we are not allowed to talk among ourselves, so the classes taught by the professors, if you have any problems, you have to talk to the professor. He will make you understand those things." But Sahil also recognized that not all lectures were equally effective; rather, Sahil most appreciated professors whose lectures were well-prepared and focused on providing examples and ideas that answered *why* something worked:

> The professors who are not that interesting, they would just come to classes and write down their notes, and try to communicate as much as possible, and then the class is over. But the interesting professors, they were more into like, they were more into talking about intricacies of the theories, like for an example, why do we set a null hypothesis of a specific form.

As such, Sahil envisioned himself being in the latter category by focusing on the *why* of statistics in tandem with learning how to apply certain concepts.

Sahil viewed homework assignments and projects as opportunities to put theory into practice and occasionally even collaborate with other students. His own school projects varied between more applied topics and theoretical topics, often using C, R, Matlab, or Python. For one project in particular, he had a group member from a Biology program who shared her own data for use in doing a regression problem. That project stood out to him as offering a lot of flexibility in letting them define their problem, identify variables of interest, and set up their analytical design.

To summarize, Sahil had deep experiences with the more theoretical and mathematical content involved in statistics. He enjoyed the occasional opportunity to work with practical problems requiring autonomy in decision-making, but he spoke most highly of courses immersed in understanding why certain concepts or procedures took a certain form. His initial philosophy toward teaching statistics is summarized well in this statement from the first interview: “I plan [to] spend as much time as possible in lecture and covering the concepts, and then let students do the homework where you get to let them apply the concepts they have learned.”

Sahil’s disciplinary views. Sahil articulated perspectives of statistics with close connection to mathematics and logic. Having earned a B.S. and M.S. degree in statistics from a mathematics department, this gave Sahil much coursework experience to draw on. As a result, he brought in substantive knowledge of more theoretical and proof-related topics in statistics than the other participants in this study. His views reflected an interesting mixture of perspectives, demonstrating close attention to both contextually-flexible aspects of statistics in terms of methodology and claims, but a more objective, deterministic perspective of statistics from a more theoretical perspective. A summary of his views are presented in Table 5.8 according to the Chapter 4 framework terms.

Table 5.8. *Sahil's Disciplinary Views by Framework Description*

Framework Category	Placement
The Nature of Statistics	Primarily **Theoretical** Orientation Statistics as modeling relationships with random noise **(Extension Model)**
The Nature of Statistical Knowledge	Statistical theories as **Objective**, methodologies as **Relative** Statistical knowledge as **Complex**
The Nature of Knowing Statistics	Statistical knowledge as **Verified** Statistical practices as **Deterministic** and statistical development as **Socio-Cultural**
The Nature of Doing Statistics	Statistics as somewhat **Flexible** and **Experience-based** Conceives of doing statistics across a variety of realms

The nature of statistics: Mathematics as the basis for statistics. When asked to define and describe statistics, Sahil emphasized the connection between statistics and mathematics, defining statistics as “the mathematical approach to deal with data to answer questions related to data.” To Sahil, mathematics was equivalent to the theoretical foundation of statistics, explaining that a term like “statistical proof” was really a misnomer, as they could just as well be called mathematical proofs. Regarding distinctions, Sahil explained that mathematics, at its core, did not necessarily have to apply to real life. Even though certain mathematical concepts like integration and differential equations had applications, they could exist and be appreciated by mathematicians even without application. Statistical topics (like hypothesis testing) differ in that the application was its identity—hypothesis testing would have no value outside of application. In many ways, this description aligned with the Extension Model by suggesting statistical applications were more contextual while mathematical applications were more universal.

Sahil also noted that statistics and mathematics shared common ground in their attempt to create models, which reflected a similar perspective as Li. Sahil explained:

> In statistics, we also do some model fitting, and math, they also do some random model fitting in applied math, but they don't have the idea that, the ideology that we follow is the model should be as simple as possible with as minimum error producing. So in a math department, they don't do that. I think they all like mainly focusing on like differential equations to solve problems.

What Sahil was articulating here was the tendency for mathematics to focus on perfect models. Statistics, on the other hand, created models based on randomly sampled data and naturally contained random noise. From this perspective, the Divergent Model also described Sahil's thinking as he pictured mathematics focusing on modeling reality from assumed truths while statistics attempted to model reality from data-driven models.

Overall, Sahil shared the same deep theoretical perspective that Li shared. His experiences as a statistics major in a mathematics department seemed to influence his development as he recognized inherently similar approaches between the two disciplines. Without the same real-world experience that Mindy had, Sahil did not draw on a contextual perspective to statistical work the same way Mindy or even Li did. Rather, he discussed statistical work as being primarily mathematical work; however, he suggested that context might matter more at advanced levels of statistical work.

The nature of statistical knowledge: Statistical knowledge reflective an objective core, but prone to error. Sahil approached the standard deviation formula with a conceptual description of its purpose, describing it as a "reasonable" measure of variability for assessing the distribution of data points around the mean. To Sahil, the idea of using an alternative measure for variability, such as mean absolute deviation, was completely sensible:

> I think they're focusing more on the robust measure of spread in their problem…It's also a measure of spread. The idea is to measure how far the data varies from the center, so that is also an acceptable measure.

This articulation of standard deviation aligned with the complex perspective of knowledge offered by Li—statistical formulas were not inherently correct or incorrect, but more or less useful in given situations. According to Sahil, the appropriateness of measuring variability using standard deviation versus mean absolute deviations rested on the characteristics of the distribution and whether certain assumptions were met. For example, he said that standard deviation was an unbiased estimator when data was normally distributed, and mean absolute deviation might then be more appropriate under different conditions. In a way, Sahil was reflecting a contextual perspective to formulas as well, but with a strictly theoretical description.

Sahil's perspective on statistical knowledge being discrete versus complex depended however, on what component of statistics was being discussed. Sahil discussed theoretical advancement by the field in terms of right and wrong. On the topic of whether knowledge was developed primarily by individuals or the wider community, Sahil stated: "Collectively, the solution will be way better than what's given at the individual level. And the ultimate goal is to find the solution." In a theoretical sense, there was some semblance of a discrete view of knowledge. However, Sahil was quite clear that applying methodology and making claims was anything but objective.

> There's no right way to do [statistics], but there are good ways to do it. Depends on the person and how they are trying to work with it to get maximum information from that dataset. So that depends on the good way to do statistics, but I don't think there's any right way to do it.

Thus, Sahil's views regarding the discreteness and complexity of statistical knowledge depended on what level of knowledge and application was being considered.

In considering Sahil's extensive coursework background in more theoretical statistical and mathematical topics, he brought great expertise on the nature of theorems and formulas. In many ways, Sahil mirrored Mindy's views, except that Sahil held a more theory-centric view while Mindy held a more application-centric view. Sahil initially thought of the components of statistical knowledge that were based in logic, but he also recognized that many statistical components were constructed and held validity relative to the purpose they served.

The nature of knowing statistics: Statistical knowledge as verifiable theory, yet constructed application. Sahil offered answers similar to Kathy about the role of collaboration in the generation of statistical knowledge. As discussed in the previous section, Sahil viewed collaboration and community oversight as an important part of disciplinary advancement. He took a rather verification-centered view toward the role of this community. While statisticians may work in groups, he also believed that someone could develop knowledge individually. "I think it should be considered as statistical knowledge as long as no one is refuting it. I think if you do something and it's right, then it is certainly right." Peer review would be useful as a platform for others to check the work of others, but not to negotiate the development of knowledge. In summary, at the level of fundamental theory (which he described as mathematics), knowledge was essentially derived and verified by the community. Sahil's familiarity with more theoretical elements of statistics provided the basis of his focus in this section; however, his views about developing and applying methodology reflected a more open and constructed perspective, as documented in the next section.

While Sahil recognized a certain level of relative validity to formulas and methodology, he explained that their use and meaning shared a uniform purpose across all cultures and statistical problems. He described all statistical researchers and analysts sharing a common pursuit in trying to develop "elegant methods" to deal with difficult problems they encountered. There were "disciplinary norms" that represented good statistical practice, and Sahil believed that "any good researcher would follow the norms as such."

> By elegant, I mean more robust, not overfitting, not underfitting. I guess by elegant, I mean the method is easy to understand, and perhaps easy to employ in some cases. And it explains the difficult problem we're thinking about.

Thus, statistical formulas and methodologies may vary in their validity and purpose in different contexts, but a shared theme of modeling amidst random noise with elegant models brought uniformity to disciplinary development. The idea that statistics might look different across cultures did not align with Sahil's perception of the discipline.

The nature of doing statistics: Individualized voices among objective, tested methods. Sahil identified a crucial threshold to participating in statistics: the inferential process. In other words, statistical work hinged on understanding that we are using a sample to make claims about a population. He further stated that introductory students needed to understand the inferential process to participate meaningfully in the discipline.

The role of creativity in statistics took some developing for Sahil. At first, he responded, “I think the creativity is knowing where to use which method.” This more rigid view mapped with Kathy’s perspective that statisticians made choices much like following a decision tree, with each path possible being fairly objective and straightforward. However, Sahil began to rethink the points in statistical work that might be more subjective:

> I: So do you think that solving statistical problems is an objective process, a subjective process, or somewhere in between?
>
> S: I think it’s somewhere in between, because the objective part is (pause) no I think it’s subjective. I think it’s somewhat subjective…I think whenever someone is trying to deal with a problem, they will have their own thought processes, right?...There might be some similarity, since we all learn similar things, since it was built on us. So there will be some similarity, but where the creativity part comes into the picture, it will be different.

This interchange was an interesting turning point in Sahil’s interview. Up until this point, Sahil had largely described applying statistical methodology rather objectively. Here, Sahil recognized a sense of individuality and flexibility in the work of statisticians. Sahil now teased out disciplinary engagement in statistics as spanning both straightforward mapping of methods as well as creation of new methods:

> I think when you’re solving like tricky difficult problems, what you think is like, we already know these methods, and these methods are not already matching with this problem, but…we have to use these methods to solve this one. So, the part where we know these methods, it’s like [that]. When we have to write methodology, and when we are using these to solve this problem, that’s where the creativity comes in.

Sahil first recognized one part of doing statistics involved knowing available methods and being able to apply them to different situations. However, existing methods would not always be a close fit. In such cases, the statistician may need to substantively adapt or create a methodology to meet the needs of the problem.

Thinking of statistics as artistic was not far-fetched for Sahil. He explained, "Researchers are having their own impression on the literature in statistics as time goes by." In this way, he described the work that each contributed as being unique, interesting, and—to some degree—experience-based. There was individual choice and judgment. Since statisticians had to make decisions in which there was not necessarily a clear answer, their style or "signature" work would be different. In our conversation, I brought up his earlier statement about good models in statistics needing to be "elegant." He related this point to creativity, explaining that creating elegant models often took innovative thinking.

Sahil's pedagogical views.

Curricular reflections: Questioning the role of mathematics. Critical to understanding Sahil's curricular views for introductory statistics was his view toward the role of mathematics in the course. His initial vision for introductory statistics students involved a combination of both statistical reasoning and thinking. He recognized his own experiences and preferences toward an emphasis on the mathematics and theory undergirding the discipline, while also realizing that other students might need or prefer more emphasis on applying methods.

> What I learned in the intro statistics course, those are like the foundational statistics and the mathematics behind the methods. They worked out perfectly for me, but I have seen students who have found them difficult to deal with…I would very much like to say that [statistical reasoning] is most important, but I think [statistical thinking] is also like

equally important because…if you provide both of them, like not too much, both of them sufficiently…the student will be able to understand the idea of statistics, either by mathematics or by computational methods.

Sahil viewed both emphases working together; learning applied methods paired with the appropriate mathematical and theoretical basis for those methods would help students understand both how and why a statistical procedure works.

Sahil's deep knowledge of computational methods and mathematical underpinnings were front and center in I-2 when he completed the mind map task. When he started with the word wall, he first wrote "mathematics," suggesting an important relationship between the two disciplines. In his resulting mind map (Figure 5.4), the bubble on the left included general statistical terms that he was not sure what to do with. Terms in the large bubble he generically labeled as belonging to the class "inference." He referred to the top grouping as being the "backbone" of statistics, including terms like "mathematics," "probability," and "analysis." He described the bubble on the right as "computational approach to inference," listing techniques or topics associated with creating techniques (note that "ML" stood for "Machine Learning"). The terms in the leftover middle category were titled "inference" to represent what these computational techniques afforded us in the overall process of statistics: "So like after constructing the models, we use these things to get the conclusion."

When asked how an introductory class operated, Sahil said, "An introductory course starts from this point [left bubble]…and goes through [Computation and Inference bubbles] with a little bit of help from mathematics." He also mentioned that a few other items that could be included in the far-left bubble, including summary statistics, boxplots, and histograms. With these statements, Sahil's view of statistics was not unlike the others in seeing a category of

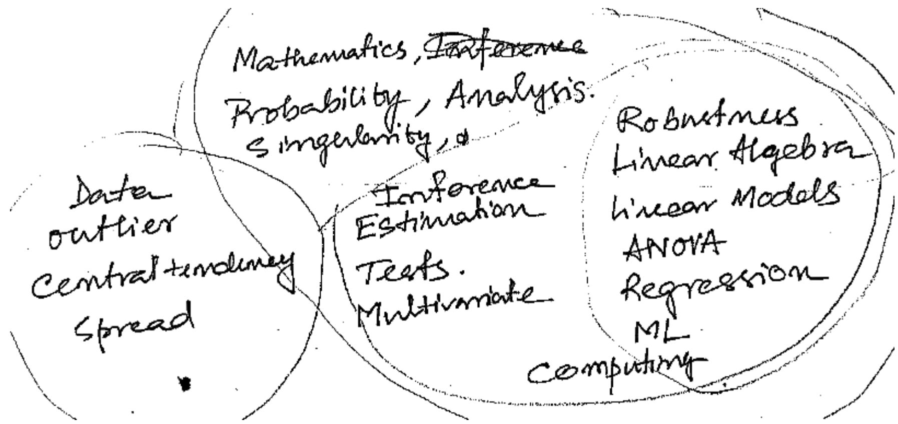

Figure 5.4. Sahil's Mind Map

basics, then moving toward inference, with mathematical and probabilistic components helping build that bridge. Primary differences emerged with his specificity in theoretical/computational topics and inclusion of more advanced applied methods. Sahil’s statistical perspective was far from the low-level applications Mindy and Kathy offered. Categorically, Sahil’s thought process was closer to Li’s, but far more comprehensive.

By I-3, Sahil’s curricular views were evolving as he realized that the students taking introductory level courses were not ready for the theoretical and computational topics he initially envisioned. He explained that the students he interacted with in recitations typically asked only low-level questions and got easily confused over simple concepts. He began adopting Li’s curricular vision:

> It’s been very clear to me that most of the students are not from a statistics background, right? So they need to learn stats to use it in their own way. So in that case, I don’t think [statistical reasoning] is that important, building theoretical parts. I think it would be better for them to be equipped with the ideas and look at everything from the perspective of statistics.

He clarified that he now privileged focusing on the inferential process (i.e., using sample information to make predictions about the population) and emphasizing basic procedures.

His written and ranked goals in I-4 demonstrated this evolving dual emphasis on procedures and basic conceptual ideas (Table 5.9). Under his written goals, he listed "how to deal with numbers methodically" to reflect his belief that students needed to practice basic calculations and procedures, and he also listed "understand how or why statistics works" to represent the conceptual component. He also included two ambitious goals, "how to bring the best out of raw data" and "how to use tools for statistics," to represent his hope that students would begin to analyze and process data in meaningful ways.

Table 5.9. *Results from Sahil's Course Objectives and Learning Goals Task*

Initial Written Aims	Course Objectives	Learning Goals
How to deal with numbers methodically Understand how or why statistics works (parameter estimation, regression modeling) How to bring the best out of raw data How to use tools for statistics (like a calculator or Excel)	1) View statistics as a process of designing a study, collecting data, analyzing data, and reporting 2) Learn how to use and understand statistical models 3) Understand basic probability and distribution theory 4) Recognize role of randomness in statistical design 5) Awareness of ethical issues 6) Link probability to statistical inference 7) Be critical consumers of data-based arguments in the media 8) Recognize the omnipresence of variability in daily life 9) Appreciate the mathematics behind statistics	**Not very important** - Complete tests by hand using statistical tables - Elementary coding - Develop deep understanding of sampling distributions - Conditional Probability **Moderately important** - Using calculator for various functions - Critique study claims - Understand the process of statistics - Collect data - Write a full statistical report - Complete a project **Very important** - Use software to create visual display and interpret results - Finding areas under normal curve - Identify questions that can be answered using statistics - Binomial Probability - Understand different methods of sampling

Noteworthy in his course objective rankings is his choice to place "appreciate the mathematics behind statistics" last. He explained: "students need to know how the testing method works on data, but for an intro course, I don't really believe they need to know how we have landed into that method, and not any other type of method." Citing the limited mathematical background of students, Sahil explained that mathematics beyond basic computation and straightforward procedures should be reserved for higher-level courses. He also gave high priority to traditional curricular procedures, like finding areas under the normal curve and learning different sampling methods, viewing these as appropriate introductory practices that he had witnessed in the introductory curriculum as a GTA.

Heading into his first semester of solo teaching, Sahil was envisioning a course that included a much more applied focus. While he viewed the theoretical component as important, he now believed through his recitation experiences that students could not handle these higher-order topics. Still, as with the others' rankings, he gave high marks to process-views of statistics, creating models, identifying statistical questions, and other more advanced components. He saw these components of statistical work as central to the discipline, yet, as with Mindy and Li, Sahil experienced tension between what he thought exemplified the discipline and the content he now believed needed to be central to the introductory course curriculum.

Instructional philosophy: Lecturing emphasizes the conceptual, practice solidifies the procedural. As discussed in his background section, Sahil's initial instructional philosophy stemmed from his positive experiences in mathematics and statistics coursework. As he stated in I-1: "I've learned statistics in India, and I enjoyed it, so my idea is, students will probably also enjoy that thing. So that's why I thought spend as much time as possible in lecture and covering the concepts." This contrasted with the recollections of Mindy and Kathy, who both labeled example problems and individualized practice in class as helpful and lecturing as generally unhelpful. Instead, Sahil wanted to devote 70-80% of his class time to lecturing, where he intended to dig into the concepts and theory.

Like the others, he also valued instructional clarity, but privileged emphasis on theoretical underpinnings. This valuing was clear when he described his favorite department professor:

> He’s very persistent. He won’t stop trying to help explain till everyone understands it. He assumes everyone understands R coding, but I don’t know it. So the computation part is not taught all that great, but the theory part is taught great.

In this environment, students were asking questions in class (a departure from his experiences in India); however, Sahil began to value this environment more after seeing how much he and others seemed to learn from lectures. Sahil now valued both careful listening and asking “why” questions during class lectures. This was closely related to his initial privileging of statistical reasoning as a primary goal of the course.

Sahil underwent notable change in his views of teaching and learning by the end of his second semester (see Table 5.10). These changes reflect several considerations. The first was his move to having students follow more procedures and rules; he justified this change by saying that students in these courses were not as capable as he originally thought in their ability to grapple with more open-ended tasks. He also greatly changed his perspective on lecturing when he realized students were easily bored and not able to understand or engage with more theoretical content. Third, he began to shift his emphasis on assessment as almost exclusively testing to a more nuanced view of assessment through projects and alternative assignments.

This more balanced instructional view complemented his emerging curricular view: Lecture is for concepts and background, while in-class activities or out-of-class assignments are for practice with procedures and applications. This emerging instructional vision was not without caveats. When asked in I-3 what concerns he had heading into his solo teaching semester soon, Sahil responded that writing an appropriate balance of questions might be difficult: “I think not really difficult problems, but the problems that would really reflect if they’ve understood the concepts or not.” Furthermore, if students were not engaging and learning the concepts and theory in lecture, he felt he needed to adjust his course vision. Like Li and Mindy, Sahil also wanted his students to complete projects in the course. However, Sahil was also honest that he was not entirely sure what that would look like and when he would be ready as an instructor to enact that plan.

Table 5.10. *Sahil's Survey Responses on Key Items*

Question	I-1	I-4
Most students learn best when they try statistical problems using their own ideas before learning formal methods (like t-tests and Chi-Square tests).	3	2
Most students learn more from a good lecture than they do from a good activity.	5	2
Student grades should be determined primarily by individually completed homework, quizzes, or exams.	5	3
Students should complete a statistical project in the course.	3	5

Sahil began to ascribe higher value to in-class activities, stemming from his positive experiences facilitating activities as a recitation instructor for the GTA Coordinator’s course. “Whenever [the GTA Coordinator] gives out the activities for one sample [confidence] intervals or hypothesis testing, students would be really interested in trying to solve those problems.” He wanted to spark that same student engagement in his own class, and he believed that including some of these same activities in his own classes would be a good start.

When seeking to understand how Sahil's pedagogical views changed over the year, it seems his own observations of students in his recitations and the GTA Coordinator's course structure were critical influences. Sahil readjusted his view of what introductory students could handle and reasonably accomplish in a course. While he had initially assumed more statistics majors would take these courses, he discovered that these courses were almost entirely non-majors. He also implicitly adopted many of the activities and questions from the GTA Coordinator's course as a guiding model for the kinds of tasks he should include in the course. Some of these observations led to clear pedagogical conclusions: introductory students may not learn best from a lecture. Other observations led to more questions: how do you balance procedural items with conceptual ideas?

As touched on in the next chapter, Sahil found tension between his developing pedagogical views and his more settled disciplinary views. Even though he held a more theory-centric view of statistics, the course he was assisting with and teaching seemingly did not have a place for some of these ideas. It seemed Sahil believed that an introductory course would either focus on theoretical ideas or procedural ideas, with no middle ground or alternative vision to draw from instead.

Summary and Discussion

Initial views. The participants articulated common ground on a number of disciplinary components. All four recognized statistics as carrying meaning in its applied nature (though their views about mathematics reflected less uniformity on this matter). The participants viewed (or were at least open to viewing) statistical formulas and methodology through a socio-cultural lens, where the development and validity of statistical knowledge was rooted in the types of problems encountered and perspectives held by different communities (Diamond & Stylianides, 2017).

The participants also recognized an important contextual element to validity and appropriateness in statistics.

The participants also shared several commonalities in their views toward teaching statistics. With exception to Sahil's I-1 lecture-centered vision, the participants collectively valued opportunities for students to participate in activities or discussions in class, aligning with the views of many statistics GTAs surveyed by Justice and colleagues (2017). All spoke at length about their experiences as students and the models of teaching they witnessed first-hand (DeFranco & McGivney-Burelle, 2001). They also defined respect for students and good communication skills as essential to good teaching.

Along with these areas of shared experiences and insights, the participants also brought diverse sets of experiences that allowed for striking differences in how the GTAs initially conceptualized the purpose of the discipline or what learning goals should be privileged in an introductory course. One distinguishing influence was the participants' differing experiences with statistics outside of a classroom setting. Most notably, Mindy attributed her internship experiences to many of her views about statistics, allowing her to see statistical problem-solving as something that was flexible, individualistic, and even creative to some extent. In contrast, Kathy primarily saw the procedural, objective tasks she completed in her own coursework as indicative of statistical problem-solving. Li and Sahil's lack of statistical experience outside the classroom pushed them to focus on their coursework, but their coursework seemed to reflect a much more theoretical orientation to statistics rather than an applied perspective. Their theoretically-dense coursework also allowed them to understand statistical formulas to be constructed and valid relate to the nature of the data they were being applied to—a perspective Mindy and Kathy had never deeply considered before this study. Li additionally did personal readings that acquainted him with philosophical ideas about the nature of the discipline that supported his rich and detailed conceptualizations of statistics.

Furthermore, the participants' various disciplinary orientations and diverse classroom experiences allowed for differences in their initial pedagogical views. Mindy gave highest preference to statistical thinking, Li personally valued statistical reasoning while also expressing some form of statistical literacy as possibly the ideal route for introductory statistics, Sahil valued a combination of statistical reasoning and thinking, and Kathy liked all three equally while also believing that students needed to learn procedures and basics. There were also differences in their initial classroom visions, with Sahil imagining a lecture-heavy introductory course, Kathy and Mindy each wanting to engage students in lots of example problems, and Li being unsure what his course would look like.

Shared experiences and pedagogical convergence. Despite these initial differences in instructional visions, the participants all seemed to converge in pedagogical views across the year due to the shared experiences they had in the department. As members of the department community, the GTAs were immersed in the teaching practices and introductory curriculum being displayed in the department. While the participants tended to use first-person singular pronouns (e.g., *I, my*) during their first semester, they gradually started to use more first-person plural pronouns (e.g., *we, our*) to refer to introductory course curricular priorities and best teaching practices. In particular, the GTAs took up the GTA Coordinator's notes as the default representation of an introductory course curriculum; Li, Kathy, and Sahil had no introductory course experience to draw from otherwise. Mindy had taken AP statistics in high school, although her reporting of that course had little distinguishable differences from the GTA

Coordinator's course structure (i.e., primarily lecturing and worked-out example problems with occasional in-class activities).

The teaching workshop exhibited indirect influence on the GTAs' views about teaching and curriculum, serving primarily to reinforce or emphasize certain views that the participants seemed to already articulate. Overall, the workshop took a rather agnostic view toward high-quality teaching, meaning that the content of the sessions focused on general tips for how to interact with students respectfully and communicate clearly, but little in the way of content-specific pedagogy, discussions of student thinking, or hard statements on how much time GTAs should spend in lectures. All four participants took "respect for students" as the key takeaway from this workshop. Additionally, the participants all highlighted "the keys activity." As a reminder, this activity had workshop participants report how many keys they had with them; the GTA Coordinator then used the data to create a histogram and find summary statistics. While the four GTAs in my study had experiences facilitating activities in recitation, this one was different in that it involved data collected from the class and, as a result, fostered a more in-the-moment nature to the activity rather than something pre-packaged. They all viewed this as a fantastic example of how to engage students in a contextual example.

In addition to influences from the GTA Coordinator, the participants viewed examples of instruction that varied in presentation format, but not necessarily varying in opportunities for sense-making. Throughout the interviews, the participants readily discussed aspects of teaching that might better be viewed as effective *styles*, rather than effective *strategies* to promote rich statistical sensemaking. In the wake of a teaching workshop that remained rather agnostic about what constitutes effective teaching, the participants' emphasis on these more general and non-discipline-specific practices is not surprising.

The GTAs naturally looked to their own teachers and professors as models for instruction. These models, however, did not appear to exemplify many reform-oriented approaches toward teaching mathematics or statistics. Still, these models of instruction reflected diverse instructional *styles* and gave the GTAs a deceptive spectrum of worst to best from which to judge instructional effectiveness. The best teachers exemplified clear communication skills, kind dispositions, and desire to do their best. For example, all four spoke highly of the GTA Coordinator's teaching ability, with some referring to her as among the best teachers of statistics, yet when pressed to explain, the only justifications were that she was "nice," "clear," and "respectful." Similar descriptions were used for a favorite graduate level professor in the department. And while these are certainly important and valued characteristics of a good instructor, such descriptions fall short of the model for an effective instructor (Borko & Putnam, 1996), much less an effective *statistics* instructor (ASA, 2016). Conversations about more general descriptions of teaching activities, rather than a focus on the relationship between instruction and learning, appears common in mathematics and science GTA training settings (DeFranco & McGivney-Burrelle, 2001; Gardner & Jones, 2011).

Alternatively, when the topic of bad teachers and instructors came up, the participants responded with more superficial noticing rather than substantive understanding of what went wrong in these cases. For example, Li reflected on his visit to another GTA's course during spring semester, which he described as boring; his takeaway was that he would be a more interesting instructor. When I pressed him for how he would be more interesting, he said that he wanted to involve students more in his lecture and make the content more interesting to them; but as seen in Chapter 6, Li's student-centered teaching practices did not generally go beyond providing practice problems for students to complete in class.

The GTAs also had common experiences working with students in recitations and facilitating activities and quizzes provided by the GTA Coordinator. A key takeaway from their recitation experiences was the perception that many students have deficient mathematical knowledge, have no interest in hearing about why a particular method works, and are simply concerned with getting right answers. When I asked Mindy to elaborate on exactly what it was so many of her students struggled with, she responded:

> Anything with numbers. Division, fractions, finding the mean…just critical thinking, unless they've seen this problem asked the same way, they're like, I've never seen this, what is this? Ok, we just did a problem like this. Oh, but it's worded differently. Not being able to understand what it's asking instead of relate it to other questions.

Mindy and the others were all discovering that students in these courses struggled not simply with college-level mathematics and statistics, but with high school and even middle-school mathematical content.

These common observations by the participants yielded changes in their curricular views. Even though all of them valued statistical literacy, thinking, and reasoning as important goals, they now began to converge on basic procedures as a necessary and fundamental element of the course. Working example problems and assigning computationally-focused problems seemed unavoidable. With the GTA Coordinator's notes, activities, and quizzes already supporting this emphasis, the GTAs' own observations only served to reinforce a focus on procedures and computation.

A closer look at each of the participants reveals important pedagogical distinctions and preferences. Mindy still privileged statistical thinking as the ideal introductory course goal. Sahil still spoke highly of integrating interesting conceptual elements into his lectures. Li wanted to give his students a sense of statistics that helped them understand the discipline, and Kathy wanted to provide her students with a lot of practice over the basics. But without support toward nurturing these visions or diverse instructional models within the department, there was a clear instructional convergence toward a computationally-centered, procedurally-heavy course (Figure 5.5). Several of the participants liked the idea of having students evaluate data-based claims in the media, complete a project, or analyze data using software, but these components were now seen as too advanced.

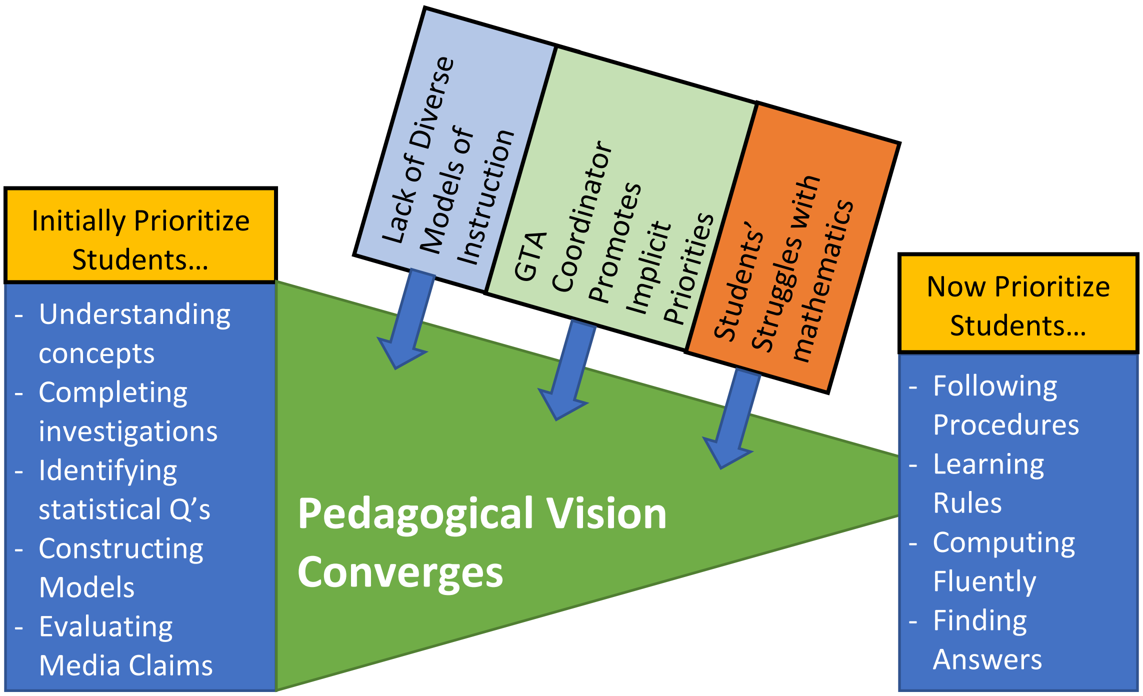

Figure 5.5. Process of Pedagogical Convergence

As documented earlier in this section, the GTAs more frequently dismissed the capabilities of students to engage productively in open-ended, complex tasks—in part due to lack of motivation and in part due to a lack of prerequisite mathematical knowledge. The disciplinary perspectives they had articulated were seemingly separated from the introductory course curriculum. The GTAs now believed introductory students needed more focused attention on computation, rules, and procedures, with interpretive and conceptual understanding perhaps being more of an advanced goal. Sahil described this compartmentalization: "I think for higher level courses, the main aspect is not to teach them more stuff, but the higher-level stuff is teaching them good stuff, better stuff." Kathy and Li similarly expressed that introductory statistics should specifically address "the basics," which included "calculations" and helping students improve at "getting correct answers." I describe this implicit separation between the nature of statistical work at an advanced level with the nature of statistical work at an introductory-course level as *disciplinary compartmentalization*.

While studying the content knowledge of statistics GTAs, Noll (2011) explained that many participants were compartmentalizing the theoretical perspectives of statistics being nurtured in their graduate courses from introductory content. The GTAs were unsure how to use their theoretical and procedural knowledge to address several conceptual tasks involving sampling variation. Consistent with those findings, the participants in this dissertation study likewise compartmentalized their personal disciplinary perspectives from the work of students learning introductory statistics. In many ways, this compartmentalization mirrors findings from Speer's (2008) case study with a GTA who perceived mathematics as beautiful and flexible but struggled to translate this perspective to the mathematics he taught. This compartmentalization did not require the participants to necessarily change their disciplinary perspectives, but to simply separate them. Against Mindy's judgment that such a course was turning students into "robots," she still seemed to think this is was all that her students could handle. In Chapter 7, I discuss the implications of this compartmentalization and how current views of learning call for merging of disciplinary practice and learning activities.

CHAPTER 6

MAKING SENSE OF PARTICIPANTS' INSTRUCTIONAL DECISIONS

Chapter 5 provided a glimpse into the experiences and views of each participant as articulated across the fall and spring. In Chapter 6, I turn to the experiences and reflections of the participants during their first solo teaching semester during the following summer. As discussed in Chapter 5, the participants' pedagogical views began to converge toward a shared instructional vision for introductory statistics before solo teaching. Their teaching practices likewise reflected this convergence. I begin by presenting case-specific findings that unpack important connections between each participant's experiences, views, and teaching practices. Then, I summarize findings across this chapter relevant to answering my fourth research question: "How do the participants' disciplinary views relate to and inform their instructional decisions and practices? What other influences inform their instructional decisions and practices?"

A Closer Look at Each GTA's Instructional Decisions

This section briefly visits the experiences and instructional decisions of each instructor to provide more insight into influences on each instructor's teaching practices. In the case of Li and Sahil, I was able to collect richer data to document their roles as in-class instructors. In the case of Mindy and Kathy, these accounts are shorter and less detailed due to the scarcity of data I was able to collect from their online courses. However, I do briefly discuss their experiences and frustrations over the limited decisions they made.

Li's instruction. Shortly before beginning his solo teaching semester, I asked Li how he would structure his class time. Li responded that he hoped to provide his students with plenty of time to complete activities and practice problems, much like the recitation component of the GTA Coordinator's course. He planned to have students spend the middle 20-30 minutes of each class period on such work. The COPUS results reflected this plan, as Li spent 55-60% of his class period presenting (reflecting a mixture of lecture and demonstrated example problems), about 30% on student-completed worksheets and occasional activities, and about 5-10% in classroom talk (typically student questions followed by responses from Li), and the remaining 5% in administrative details. Typically, student questions focused on clarifying details from Li's examples or asking about whether something would be on a test. Li also engaged with students while they worked on individual problems or activities, but these engagements typically revolved around verifying procedures and checking answers.

Table 6.1. *Li's COPUS Results*

Instructor Doing	Instructor %	Student Doing	Student %
Presenting	56.2%	Receiving	59.4%
Guiding	37.4%	Students talking to class	11.4%
Administration	5.5%	Students Working	26.9%
Other	0.9%	Other	2.1%

At the beginning of his solo teaching semester, Li had hoped to develop many of his own activities, worksheets, and instructional materials; however, he resorted to using the GTA Coordinator's materials almost exclusively. For this reason, an analysis of the tasks that Li administered to students in class provides only limited insight into Li's instructional decisions. Nonetheless, these were tasks that Li chose to implement; he had the freedom to create, adapt, or administer whichever tasks he wanted. I was able to collect and code 11 tasks from Li's course. These results are presented in Table 6.2.

Table 6.2. *Coding Results from Li's Tasks*

Task	1	2	3	4	5	6	7	8	9	10	11
Openness/ Flexibility	1	0	2	2	1	2	0	2	2	2	1
Contextual Integration	1	0	1	2	1	1	0	1	1	1	1

Most of these tasks included some sort of contextual setting, but context was typically integrated only at a superficial level. In other words, the variable names were almost always replaceable without changing the nature of the task or the form of the requested solution. Only one task achieved level 2 on contextual integration. This task asked students to choose two variables from a multiple regression analysis to test again, using their knowledge of the context as one factor for making their decision. Outside of this question, context held little influence in the task.

Regarding openness and flexibility, Li frequently asked students to complete procedural problems for which there was one right answer and one solution path. Occasionally, students were also asked to interpret a value or result in context. These opportunities provided some opportunity for open-ended thinking, but the solution manuals and accompanying note packet typically revealed a fill-in-the-blank-style template for answering these types of questions. Mirroring what Li mentioned before, he preferred activities and homework questions were aligned with quiz questions; this question format could be used again directly on quizzes and objectively graded using the template. These considerations make sense given that these tasks were written by the GTA Coordinator for use in a large-lecture statistics course with first-semester GTAs grading and facilitating, but Li was quite satisfied with these tasks for use in his own class.

As a first-semester solo instructor, Li still grappled with many of the same issues and concerns he had as a recitation instructor, including difficulties communicating clearly with students. He reflected on his initial perceptions that he simply needed to tell students how statistics work, but now that he was in the classroom, he realized it was more complex than that:

> I was just thinking I'll tell students what I know about statistics, I know everything about statistics in the intro level, so just to tell what I know. That could be simple, but it turns out that is not the truth. Students as I talk about don't have math or statistics background, so I have to deliver everything in another way.

Li quickly realized that students would stop paying attention, get easily confused, and check out of his presentations on concepts and theory components, which he attributed, at least in part, to their mathematical deficiencies. Due to these deficiencies, he now believed that students were incapable of productively grappling with problems without being provided formal methods. In the initial survey, Li strongly agreed with the statement, "Most students learn best when they try statistical problems using their own ideas before learning formal methods (like t-tests and Chi-Square tests)." He later pulled back his enthusiasm:

> I think the try your own idea is really important, which is why I give it 5 [strongly agree], but after I started teaching, I found especially for non-statistics major students, it's impossible for them to get their own idea, like t or z test. They don't have the background here. So the ways to solve these problems are not trivial for them at all. *Even to let them think is probably a waste of time.* There are so many things before they need to learn.

Li's limiting views of students (a point expressed by all participants) had led him to believe that students would not be able to handle tasks that did not have clear directions and solutions.

One way that Li tried to reach students more effectively was by offering more example problems and making connections as clear as possible between the content he presented and the questions they completed on exams. He explained: "The best way for [students to do well on a] test is remembering all formulas…[however], remember[ing] or copying formulas is a way to avoid understanding things. Though it's not good, but here it happens." Li was discontent at the thought of his students only learning to follow procedures, but his assessments were constrained on this front. Since this became his default means of assessment, it made sense that he would build his class time around providing examples and feedback to students on following procedures.

Still, Li did (and felt he should) address the basis for these procedures and ideas. To accomplish this, he believed he needed to provide simplified explanations with fewer distracting details. Even though Li described statistical theories and formulas as holding contextual and relative validity, he worried that complex contextual examples may add confusion. Li's approach to teaching sampling distributions exemplified this simplified perspective. He introduced sampling distributions by first providing a definition, followed by its properties. To explain the first property—that the mean of a population will be equal to the mean of the sampling distribution—Li drew a rectangle on the whiteboard that contained one red ball and one blue ball (see left image in Figure 6.1). He explained that if he assigned numbers to each ball (1 for red and 2 for blue), then he could randomly sample one ball, record his results on a histogram, and this histogram would represent the sampling distribution. He pointed out that if he took the mean of all of these results, the mean would be 1.5, which would be the same as the mean of the red and blue ball.

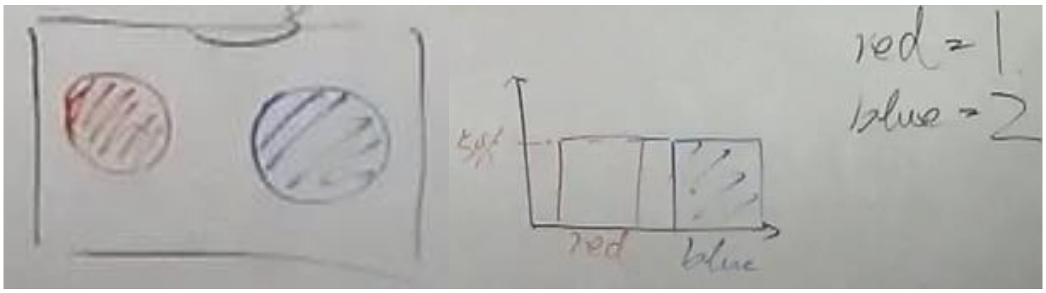

Figure 6.1. Li's Drawings for Sampling Distributions

As he wrapped up this explanation, a student asked for clarification:

S: Why does the blue get 2, I know you just picked it.

L: So here I just give each color a number, otherwise, we can't calculate it right.

S: So could both of them be 1?

L: It can be 1, I just want to make different colors different in value. Blue can be 0, it can be negative 1, it can be anything.

S: But what does that value represent?

L: The value in this case is just making it easier for our calculation, because it stays, we cannot calculate the mean, right? We cannot say blue times ½, we cannot get a number in that case right, so I just gave them a value. We can give them different values. 1.1 1.2, it doesn't matter.

S: Is that the value of X?

L: Of X? Yes, that's the value of X

S: So those will be given correct? So if it was on the test?

L: Yes, those will be given, but these two are what we get if we have the 2 box and have equal chance of having them. So the probability is based on the population numbers, we must be given the numbers because in our study, we'll rarely encounter some observations which are not numbers or values. So if we want to measure them, study them, and apply math model on them, we must assign them certain values, which is why I gave these certain colors certain values.

As the exchange continues, it becomes clear that the student is centrally concerned with being prepared for the test. Li had other goals in mind:

> I'm trying to let them know the relationship between the distribution and simple random sample…we have a simple random sample, it should have one value… I reduced the difficulty of the model so students can focus on the relationship [between a] simple random sample and its distribution.

The segment continued with Li creating a histogram for all sample results from drawing two balls with replacement and using a tree diagram to represent all possibilities. When I asked Li to comment on students' thinking in this segment of the lesson and why students were asking questions, Li explained: "The reason why there is a confusion is because they don't have enough experience with a math model." Li believed he needed to set this theoretical foundation for them as a prerequisite to making sense of sampling distributions. As he alluded, context might add confusion, and he believed a trivial example would be easier for students to digest.

As an introductory instructor, Li had hoped to give his students a "sense of statistics." He remarked that while he personally wanted students to learn more theoretical and statistical-reasoning-related components, that an introductory course may not need to go into this depth. Yet, from observing his course, I found much of his focus to be mathematical, rather than present distinctly statistical elements (such as the example previously described). When I shared this observation with Li in I-6, he responded:

> I would say that's kind of habit. I teach the way where I was educated. When I was doing teaching things, I automatically choose the way I was most familiar with…After the class, I know I talked about too much math today, and students were really confused. They have the really confusing face. But sometimes, I just do it unconsciously. When I start a topic, I want to tell students *why* it happens.

Li felt compelled to provide these details, even though he explained that this was not a priority, drawing from his own experiences as a student in his undergraduate mathematics courses.

Connecting Li's disciplinary views to his instructional decisions, Li held a more theory-centered perspective of statistics, aligning with his curricular valuing of the underlying mathematical ideas. He also discussed statistical formulas and methods as being constructed and holding validity relative to the situation, rather than being objectively true entities. Additionally, Li expressed that statistics was inherently tied with the contextual, and that using statistical tools should be a flexible activity. Yet despite these characteristics of statistical knowledge development and problem-solving, Li approached introductory level concepts like sampling distributions as if they were objective, universally-existing entities rather than contextually-meaningful entities. He believed that simplified presentations that limited contextual examples would clarify the underlying concepts. Additionally, more example problems gave students more practice with using formulas, with contexts acting merely as a feature to each problem.

Sahil's instruction. Sahil engaged in teacher-centered presentations and administered problem-solving sessions for similar proportions as Li. While he had initially thought he would lecture for up to 80% of class, he scaled this plan back some to make more time for students to complete practice problems and activities (again, using many of the GTA Coordinator's materials). His COPUS results are presented in Table 6.3. Li ended up spending 60-65% of class in lecture (composed primarily of his completing example problems for the class), about 10-15% of class for student-completed activities and worksheets, and a considerable amount of time answering questions (over 20%). Student questions were a regular feature interspersed throughout Sahil's presentations but like Li's classroom, these questions typically focused on clarifying details and ensuring students were prepared for an upcoming exam. Sahil made it fairly clear that many of the conceptual details he shared in class would not be tested.

Table 6.3. *Sahil's COPUS Results*

Instructor Doing	Instructor %	Student Doing	Student %
Presenting	62.9%	Receiving	64.0%
Guiding	33.8%	Students talking to class	22.9%
Administration	3.3%	Students working	11.0%
Other	0.0%	Other	2.1%

While Li had initially considered making some of his own instructional materials as a solo instructor, Sahil was happy to adopt the GTA Coordinator's materials. He was enthusiastic about the activities and believed they were quite effective for student learning. Results from his eight collected tasks are presented in Table 6.4.

Table 6.4. *Coding Results from Sahil's Tasks*

Task	1	2	3	4	5	6	7	8
Openness/ Flexibility	1	0	2	0	2	2	1	1
Contextual Integration	1	0	1	1	1	1	1	1

The set of tasks I collected from Sahil were essentially the same as those collected from Li. The only modifications made were more administrative in nature, such as adjusting the length of the task or the placement of the tasks in the sequence of instruction. The nature of openness and flexibility in addition to contextual integration were substantively the same for both coding results.

While Li acknowledged the GTA Coordinator's influence on his class through his borrowing of her materials, Sahil went farther by expressing that he hoped to emulate her teaching style. When I asked him whether he would change anything in her class notes as he used them, or explain things a different way, Sahil expressed that he probably would not do anything different. He also acknowledged her assessment structure as influencing his mindset:

> Originally, I was thinking about just having one midterm and one final, but then [the GTA Coordinator] told me it would be better to have more quizzes to keep students on track, so I'm taking 7 pop quizzes. And two of the lowest grades will get dropped.

Sahil's two-semester experience as a recitation instructor for the GTA Coordinator was an important stepping stone in his instructional vision. He found this course to work well and saw little to improve.

While Li and Sahil both tried to organize group work in class where students could talk to each other as they solve problems, neither one of them mandated it. Sahil explained: "I thought to have them engage in the discussion; they joined the group [or] solved their problems by themselves. So then I thought it would be better to leave them alone where they are comfortable." In other words, Sahil liked the idea of students working together, but this collaborative effort appeared only a peripheral preference when he considered his emerging learning goals for students: students completing tasks and arriving at correct answers.

Despite Sahil's deeper understanding of the content and desire to instill that in students, Sahil's instruction gravitated toward a rule-based approach. In one class I observed, Sahil stated that when completing a Chi-square test for independence, at least 80% of cells needed an expected value of at least 5 (a rule he found in the course's suggested textbook). When I asked him about the basis of this rule and its importance in teaching, he said: "Yeah, it could be changed, but in terms of intro statistics students, I didn't want to give them the vibe it can be changed because it could make it more confusing to them." For similar reasons he provided a threshold R^2 value of 30% for students to use in determining whether the simple linear regression model was more helpful than the trivial model (i.e., no predictor coefficients). He responded: "It's always better for students in introductory statistics to have a specific number to compare."

Even though Sahil wanted students to understand these measures and tests, he was unsure how to assess that understanding. For example, when Sahil was teaching students about hypothesis testing and making judgments using p-values, he opened the topic with a lecture on the meaning and basis of p-values. A student asked him if they would need to explain the meaning of p-values on the exam, to which Sahil responded, "No. You simply need to be able to fill in the blanks to the sentence, like the example we just did." True to this statement, Sahil had students complete a worksheet in a following class where they practiced making correct conclusions based on the p-value and significance level provided. The fill-in-the-blank statement students filled in was as follows: "If the population mean [insert variable] is indeed [insert null hypothesis], then due to sampling variation alone, at most [insert p-value] of all possible sample mean [insert variable] are expected to be [insert alternative hypothesis] when the samples consist of [n participants] each." Even though context was attached to each problem, the context had no bearing on students' arriving at correct answers; instead, students simply needed to complete the correct calculations and plug in the information appropriately. His quizzes and exams followed suit: "For the quizzes, I mostly try to have the questions as simple as possible, like multiple choice or fill in the blank with simple words."

Still, Sahil was consistent in his pre-teaching goal to help his students understand the inferential process. As he explained in I-6:

> In an intro course, they are learning how statistics works. I repeated in the class that we are using statistics because we don't know anything about the population, and we have a small part of the population as a sample. Now we are trying to use this sample to predict

> the shape or the nature or the characteristics of that population, so in order to do that, we are using these different methods.

The last part of this statement reflected Sahil's approach to meeting this goal. By acquainting students with various tests and procedures, he hoped to give students a glimpse into the inferential process. While many of the statistical tests used in the course involved assumptions, Sahil remarked that it was better to have students accept these assumptions without question for now, as discussion on such matters would distract from following the process.

Like Li, it seemed Sahil's disciplinary perspectives applied to upper-level content, while introductory statistics became a distanced prerequisite to these upper-level courses. Despite expressing a complex view of statistical knowledge in which it was not always reasonable to address things as "right" and "wrong," Sahil continued to downplay students' needs to understand beyond rules and procedures in their pursuit toward right answers. Likewise, context was merely a feature to engage students rather than a critical component of problem-framing and reasoning in the course. The flexible and experience-based approach to doing statistics that he advocated in his disciplinary views simply did not apply at this level.

Mindy's instruction. As an online instructor, Mindy heavily depended on the format modeled to her by the GTA who served as an online instructor during the spring semester. As an online mentor for her class, Mindy described her orientation into the online format as simply learning what students submit, gauging the amount of emails to expect, and some of the common difficulties students have with the system, Launchpad. Nowhere in her online training was their discussion about how students learn content. Rather, it was assumed that Launchpad was designed so that online instructors did not have to worry about such matters; instructors were simply available to provide extra help when students needed it.

The GTA Coordinator influenced Mindy's work to the extent that she and Kathy were expected to integrate calculator work into the course. Since Launchpad emphasized calculations by hand and the use of statistical tables, it was up to Mindy and Kathy to decide how to integrate calculators into student work. Mindy took up this request by adding a calculator tutorial to the course website and adding an additional set of problems for students to complete involving finding areas under a normal curve with z scores.

Like the others, Mindy was struck by the mathematical difficulties her students exhibited. Mindy lamented that "[Students] don't come in with a high enough math background to understand" the things that Launchpad was teaching them and assessing them on. She believed that they would struggle to solve problems informally if given such tasks. She also believed it might be good for at least some of these students to be given data and asked an open-ended question. But she also believed that other students in that situation would get confused or flustered.

Mindy also voiced poignant dissatisfaction with the questions Launchpad asked students. While she personally valued goals that aligned with statistical thinking and somewhat with literacy, she found the questions on Launchpad to be primarily assessing statistical reasoning and felt that "it doesn't even do it very well." She determined that the course was much like a mathematics class, where students needed to demonstrate fluent computational skills and run through an exorbitant number of different tests to be familiar. Yet, she wished for something different:

> I thought Launchpad had way too many topics to get a handle, especially in six weeks. It seemed like a short time, and Launchpad just had more topics than we typically teach in class, which did not help with six weeks. Like going into Poisson and stuff. They also

went into 2 prop, 2 sample—too many tests for these kids to get a handle on…So cutting that down.

She did not believe her students were actually prepared to do any statistics by the time the class was over because they had really only learned a lot of procedures that they would simply forget. Furthermore, the focus on computation was taking away from other things she valued: “We can't teach the math and all the other things, we just don't have time to do that.”

While my dissertation primarily documents how disciplinary views influence teaching practices, Mindy shared an example of how that relationship was slightly flipped. When asked whether she viewed doing statistics as more methodical or more flexible, Mindy responded that she *now* viewed it as slightly more methodical. She noted this was a change, and that when she first came in, she would have said it was more flexible.

I: So do you think that little change has been assisting with a class, seeing questions that [the GTA Coordinator] uses, that Launchpad uses?

M: Yeah definitely. This is what we do, this is how we do it. Being driven over and over and over again in my mind has led me more to methods based

I: Where would [your flexible viewpoint] be inspired from when you first came in?

M: I think it was inspired by me doing data analysis and being given a problem and being told, ok figure out this, and me being on my own just trying to figure it out, whereas now, I see more of that certain assumptions that you have to figure out what you're making, and that's how you figure out what test you're doing, so I was probably doing wrong things before.

Mindy now questioned her earlier experiences; since much of the work she was completing in her graduate program felt rules-based, she wondered if her initial perception of statistics might have been *too* open-ended.

Mindy's disciplinary views had not completely moved away from these initial flexible and contextually-driven notions. She still noted that context plays an important role in how you approach a statistical problem. However, in the introductory course environment, context primarily served as a way to attract students' interest, but not as a consideration in what process you actually follow:

> I think going through the process, it's not that different, but like grabbing the attention of the context matters…I think that, overall in statistics, context matters; in intro level, the questions we tend to give them, it doesn't. I think the questions we give them are like, this is what you're doing.

Similarly to Li and Sahil, Mindy's disciplinary views were sidelined, but not necessarily abandoned. She recognized context mattered and that some manner of flexibility and choice had a place in statistical work. Yet, she was seeing a side of statistics that seemed exclusively methodical and rule-based. Even with these views in mind, she had concluded that these elements may not have a place in introductory statistics—even if this instructional vision went against her own judgment and pedagogical desires.

Kathy's instruction. Kathy's online teaching experiences and reflections were not dramatically different from Mindy's in terms of the aspects over which she had autonomy. Kathy also served as an online mentor the semester before and acquainted herself with Launchpad: "I went through the launchpad and all the videos, and just kind of mimicked what [current online instructor] did last semester in terms of the important concepts for the class." She remarked that dealing with students' constant technical difficulties was the most challenging part of her work.

Unlike the other participants, Kathy had never shared a fully flexible and constructed view of statistics. Therefore, it was not surprising that she did not believe it was plausible to ask students to complete a problem without learning the formal method first. Not only did this seem unproductive to do with students, she found it to against her perception of how statistical work is completed. When asked what she thought about students simply being given weight loss data from two different diets and asking whether it might be potentially beneficial to have students wrestle with this comparison before learning a t-test, Kathy responded:

> I think it's beneficial because…it's kind of showing students this is terrible. You can't make that big a claim. You need to know more information…the methods behind them would definitely be first, because you would have to know at least about p-values…It reminds me of a project we did in middle school.

Kathy was communicating that to allow students to grapple with a comparison using informal statistical reasoning would be beneficial only in demonstrating to them what they should *not* do in statistics. This response aligns clearly with her more methodical and knowledge-based views about the nature of doing statistics.

Still, Kathy did not have an altogether inflexible view toward statistical work, but her view of flexibility primarily reflected choice in picking a method rather than choice in design and adaptive use of existing strategies (or creation of new strategies). Following her view that introductory students needed careful guidance, Kathy believed that her course should focus on more methodical elements while choices should be reserved for advanced courses.

> We give [students] simple problems, like what is the average amount of rain in January. Then there's going to be simple stuff to follow; ok we do this and get a number. But the more advanced you get, the more flexible you become; different kinds of testing and analysis you can use. So once you choose the analysis, choose the method, then it's more rigid, but the more advanced the question, the more leeway you get in choosing how you go about it… my role would be here is what we're looking for, here is the question we're posing, here is the method we selected.

Logically following this model for introductory statistics would be an emphasis on procedures and rules in which students in these courses are carrying out step-by-step instructions after someone else (e.g., the textbook, the instructor) has already made the open-ended choices.

Kathy was somewhat more positive than Mindy about Launchpad and her perception of students' learning in the course. She frequently referred to Launchpad's content as "the basics," and she found some of this to be important and necessary. Her primary complaint came with the more "conceptual" content that only seemed to appear on the exams and quizzes.

> I think they deal a lot more with conceptual things instead of testing if students know how to answer the problem, so I don't like that so much. I also know there are some weird questions that deal with the interpretation of graphs, like pick the best answer. Like this isn't wrong, but there's some superfluous information…I don't think it emphasizes the calculations as much as it should in an intro stats class.

Kathy highly valued mathematical computation and straightforward elements; she disliked questions that seemed somewhat subjective or interpretive.

Like Mindy, Kathy's disciplinary views also seemed to evolve from her teaching experience. She viewed Launchpad as a curricular authority, much like the GTA Coordinator's notes. She remarked that seeing how Launchpad ordered topics and assessed items helped her see a logical sequence to the content. She also appreciated the breadth of topics the course covered and now strongly agreed with the survey statement: “Most students should learn more topics in less detail rather than fewer topics in more detail.” She explained:

> I like that they got a little bit of everything, because in undergrad, I was a math major, not a full-blown stats major, so I could only take two stat courses. When I got into first semester Statistics in Applications [graduate level course], there were concepts I’d just never heard before…if I had had that knowledge, like a little intro, this is what it is, then it would have been more useful in future courses.

Kathy appeared to be reinforcing her disciplinary perspectives that being knowledgeable in statistics was primarily based in knowing the methods. However, she still did not see practices pervading the work of statistics, such as perseverance, common sense, creativity, and critical thinking (Wild & Pfannkuch, 1999).

Summary of Teaching Experiences and Influences

Despite having quite varied pedagogical views and experiences upon entering the program, the GTAs began expressing pedagogical views by I-4 that were converging on common themes and practices carried out in the department. This convergence was due in part to lowered expectations of students’ capabilities, but in the cases of Li and Sahil, it was also clear that the GTA Coordinator had an enormous influence on their instructional approach. Furthermore, the GTAs were compartmentalizing introductory statistics as being exempt from many of the practices and ideas that characterize the discipline at a more advanced level. The participants’ teaching experiences only furthered these trends. All four participants led and facilitated courses that included frequent requests for computation and fill-in-the-blank responses and few opportunities for open-ended, interpretive thinking. Such an approach was consistent with the instruction they witnessed in the department, and they were able to adopt disciplinary and curricular views to justify this decision—with Mindy as the lone questioner.

Many of their instructional decisions were foreshadowed by their spring-semester pedagogical views. A common theme articulated was that introductory students are not prepared for the high-level disciplinary practices several of them had described and fleshed out in the earlier interviews. This was partly justified by the observation that students struggled with mathematics. Based on recitation and online mentoring experiences, the GTAs found that students were easily frustrated when directions were not clear, and the solution requested was slightly open-ended. Their experiences as solo instructors reinforced these observations. Li and Sahil believed that their students wanted instruction to be clear and aligned with exam questions. Students seemed disinterested during their presentations over theoretical and conceptual pieces, so Li and Sahil slowly adapted to completing more example problems as the course progressed. Mindy reflected that the never-ending emphasis on computation and procedures in the resources to which she had access were leading her to question her disciplinary views that statistics was flexible and contextually-driven. Ultimately, she was left frustrated with the course she was leading, as she wanted to engage students in more meaningful work. Kathy remained rather content with her disciplinary views for statistics, with her instructional vision following in close alignment.

In Chapter 7, I detail the logical next steps. Disciplinary perspectives that resonate with expert notions of statistics are likely necessary to ensure pedagogical alignment with the goals outlined by the GAISE Report (ASA, 2016). However, it is clear from these findings that such disciplinary perspectives are not sufficient to ensure this high-quality instruction. Building from the literature discussed in Chapter 2, I build a vision for statistics GTA training and professional development that I believe addresses the disciplinary to pedagogical divide outlined in this dissertation. From these propositions, I offer thoughts for future research that are specific to training graduate students and novice instructors for teaching responsibilities in statistics.

CHAPTER 7

DISCUSSION

Summary of Contributions and Limitations

Detailing a disciplinary perspectives framework. In this dissertation, I have presented a framework that categorizes different dimensions of disciplinary views relevant to statistics. As part of my dissertation study, I probed the disciplinary views of four first-year statistics GTAs using this underlying framework as a guide. My findings reveal important perspectives and disciplinary tensions with which these GTAs were wrestling as they conceived of the nature and purpose of disciplinary components. Even though several of them articulated expert notions about statistics, these notions appeared disconnected from the work they believed most appropriate for introductory-level students.

First, the participants were oriented differently to the discipline, with some having more familiarity and understanding of theoretical topics and some having more experience with applied topics. The participants also found different ways to distinguish statistics from mathematics (which I summarized in three models). These models varied in the types of problems statistics uniquely addressed and the approaches that each discipline takes to tackle those problems. Second, the participants wrestled with viewing statistical knowledge (e.g., theorems, formulas, and methodology) as consisting of universal, objective entities or contextual, relative entities. This spectrum also related with their views of statistical knowledge being discrete and straightforward versus knowledge being complex and sometimes ambiguous. Third, the participants discussed different aspects of statistical knowledge that they described as verified by the community versus others that were better viewed as negotiated and refined. Also on the topic of knowing statistics, the participants reflected varying levels of socio-cultural influence on the development of statistics; in some cases, different cultures merely encountered different problems, or cultural norms actually influenced the way experts might conceive and approach problem solving. Finally, the participants shared several different perspectives on the nature of doing statistics. Statistical problem solving may be strictly methodical, or also involve some layer of flexibility. Similarly, the expertise of a statistician may be purely their knowledge of existing procedures and processes, or it may also stem from their experience and understanding of the problem context.

Looking back at the literature regarding expert views on the discipline of statistics, there are many points of alignment. Li's divergent model for the nature of statistics describes well the statistical and mathematical distinctions presented by Cobb and Moore (1997) or Diamond and Stylianides (2017). While Mindy's extension model also reflects a contextual nature to statistical claims, her view that mathematics was distinguished by making universal claims (as well as her later articulations that mathematics does not have assumptions) does not exactly reflect the true nature of mathematics (Ernest, 1991; Greenberg, 1993). The spectrum model, which best describes Kathy's views, misses the more nuanced differences between mathematics and statistics beyond one discipline being more applied than the other.

Epistemological perspectives from the participants reflected a mixture of productive and limiting views about disciplinary knowledge and knowledge development. In particular, Kathy's views—that statistical work was primarily centered on right and wrong answers—primarily reflected a view of classroom-based calculations rather than large-scale statistical problems that are answered with measures of confidence and associated assumptions (Lindley, 2000). The more complex views of knowledge and contextually-driven perspectives offered by Li (and Sahil and Mindy to some degree) better reflect the nuanced and relative nature of knowledge (King &

Kitchener, 1994). The participants also reflected some tensions regarding the constructed nature of statistical development as they wrestled to classify components of disciplinary knowledge as negotiated or provable and discovered. Regarding probabilistic underpinnings and theoretical development, this question may be viewed as under debate; however, with regard to methodological development, experts would typically agree that methods are of a more constructed and negotiated nature, as demonstrated by the nature of peer review and collaboration in statistics publications (Diamond & Stylianides, 2017). All four of the participants did reflect some level of socio-cultural influence on disciplinary development (with Sahil questioning whether this influence made any substantive difference). While White (1997) discusses the social question with regard to mathematics, it is logical to transfer this socio-cultural influence to the development of statistics.

Disciplinary engagement proved to be an interesting ground for discussion. Many statisticians and statistics educators would describe statistical problem-solving as a flexible and sometimes creative pursuit, with experience and common-sense serving important roles (De Veaux & Velleman, 2008; Wild & Pfannkuch, 1999). From the results, it appears that the GTAs in this study were not altogether sure whether such notions were allowed in introductory statistics. Mindy was most grounded in her assertions that solving problems is a flexible and open-ended endeavor, as she was the only one who had rich, experiences addressing data-driven problems outside the classroom. Li and Sahil also understood that disciplinary development was rather open-ended, with Li going so far to say that there was something artistic about the work of making sense of data. Regarding the distinction of experts, Kathy and Mindy tended to view expertise as familiarity with many statistical tests, procedures, and rules. While deep knowledge of various statistical tools certainly represents a portion of what characterizes experts (Garfield et al., 2015), this description is incomplete. Experts also draw on their experience to find innovative solutions (Bransford et al., 2000; Schoenfeld, 1992)—a description that Li and Sahil noted. Statistical experts also make sense of statistical results with meaningful, contextually-tied implications (Pfannkuch, 2011) and are characterized by their exhibiting of various practices and mindsets (Wild & Pfannkuch, 1999).

As I make sense of the participants' responses and their alignment to notions in the literature, it would appear that the participants were reflecting several expert perspectives of statistics, even as first-year graduate students. In some cases, these perspectives were still somewhat undeveloped, and perspectives varied quite a bit across the four participants. Differing experiences and opportunities also played a role in how the participants thought within each dimension.

With these findings, I caution the reader of the limited generalizability of this contribution. As discussed in the conclusion of Chapter 4, the development of a framework and the fleshing out of different disciplinary dimensions would also be served with a grounded theory approach that probes the views of a larger group of statistics GTAs. These results tell a story rich in depth but limited in scope. Another limitation, which dually emerges as a finding, is the role of precision and specificity needed when probing disciplinary views in statistics. I was not careful to distinguish between statistical theorems, definitions, formulas, methodology, and claims when I asked many of my questions; for example, asking whether statistical knowledge should be thought of as something discovered or something constructed may be taken up differently depending on which of those components of statistical knowledge the participants were considering. While I was able to differentiate some of these components from the interviews, I now see that an instrument that accounts for these different components appropriately is likely to produce more robust results As I discuss in the next section, there is a need for future research that properly teases out these separate elements of statistical knowledge.

Pedagogical views and teaching practices. With research demonstrating important connections between an instructor's disciplinary views and teaching practices (Abd-El-Khalick et al., 1998; Speer, 2008; Thompson, 1984), I investigated the extent to which this connection might be true for statistics GTAs. With many opportunities for learning new ideas, changing their perceptions, and putting an instructional vision into practice, first-year graduate students serving as GTAs are synthesizing influential experiences and making pivotal decisions (Green, 2010; Speer, Gutmann, & Murphy, 2005). No doubt, the participants discussed in this dissertation were at a crucial crossroads for developing views about statistics and statistics pedagogy.

External influences on pedagogical views and teaching practices. In many ways, Mindy, Li, Kathy, and Sahil were expressing views about teaching that aligned with many of the findings documented by Justice et al. (2017). For the most part, they wanted to provide student-centered classroom experiences where students did more than listen—a space where students engaged in problem-solving and communal assistance. However, as Justice and colleagues' reported, desires to implement student-centered structures are often not realized in practice.

I highlight three important external factors that seemed to constrain the enactment of a reform-oriented classroom vision as outlined by the GAISE Report. First, the participants lacked a rich vision for a student-centered classroom and focused instead on more superficial instructional styles. This parched vision for instruction was due to the seemingly limited scope of instructional models with which the participants had been acquainted (DeFranco & McGivney-Burrelle, 2001; Kung & Speer, 2009). For example, Mindy and Kathy both described high-quality instruction as providing worked-out example problems and giving students more opportunity to complete practice problems in class. Similarly, Li and Sahil gravitated toward this view across the semester. The GTAs learned about domain-general tips for teaching from their own learning experiences and from the GTA Coordinator: respect your students, communicate clearly, and ensure class content and problem structures or wordings align with what is assessed. The GTAs struggled to conceptualize activities and tasks that effectively pushed students to think critically about conceptual ideas at the heart of statistics (Garfield et al., 2015), engage in statistical practices (Wild & Pfannkuch, 1999), or explore data in informal, contextually-centered ways (Pfannkuch, 2011).

Second, the participants' curricular views for statistics were not nurtured toward ambitious and important course goals. In many ways, the participants were open to important goals for introductory statistics, including the aims of statistical literacy, thinking, and reasoning. As Figure 5.5 demonstrated in Chapter 5, the GTAs had a fairly inclusive curricular vision that valued students completing projects, evaluating statistically-based claims in the media, grappling with concepts that get at *why* statistical tests and procedures work, and even a glimpse at modeling and using technology to support analysis. The participants' initial curricular views, however, were also unfocused and removed from the experiences of classroom teaching. The GTA Coordinator, whether she realized it or not, exerted tremendous influence on the GTAs' conceptions of what an introductory course should include. Even without ever visiting her large-lecture meetings[4], the GTAs assumed a rather procedural and rule-based curriculum from her class notes. As discussed in task analysis in Chapter 6, her activities were generally absent of truly open-ended problems and contextually-driven work. For Li and Sahil, these tasks seemed to

[4] Having observed GTA Coordinator's large-lecture instruction before, I know that she actually spends significant time explaining concepts, drawing pictures, and providing additional insights not seen in the notes.

provide a ceiling for what they perceived they might accomplish in class. Lack of robust discussion about introductory course content in the workshop (outside of clarifying acceptable quiz questions and discussion over grading different responses), gave the GTAs little insight about the larger, conceptual goals their students really needed. Conceptual understanding and engaging in statistical investigations were viewed as nice, but extraneous.

Third, the participants developed limiting views of what introductory students could handle. As documented in previous chapters, the GTAs would frequently find that many students struggled with computation or lacked number sense and critical reasoning skills in the context of numbers. Paralleling these observations were experiences of administering activities that often involved a significant amount of computation, lengthy procedures, and singular solution paths. Similarly, quizzes and exams written by the GTA Coordinator (designed for ease of grading) often stressed many of these aspects as well. As the participants continued to discover students struggling with such things as scientific notation, fractions, and difficulty conceptualizing the procedures they were carrying out, their perceptions focused on what students could *not* do.

Regarding the lowering of expectations, I theorize that the perceptions GTAs gathered from the mathematical abilities of *some* students may have resulted in some form of a self-fulfilling prophecy toward what *all* students could handle (e.g., Brophy, 1983). By finding certain basic computation to be hard for some, the GTAs questioned whether introductory students in general could ever handle a more open-ended or contextually-involved task. Students, then, may have simply matched the expectations for procedural work, expressing frustration or confusion whenever a task was less familiar or unclear. As shown in the classroom excerpt involving Li teaching sampling distributions, a student first asked for context or meaning, and upon finding there was none, focused on ensuring she would be prepared for the test. An expectation was set relatively early that computational and procedural mastery were valued and assessed; students were oriented to viewing statistical problems as having right and wrong answers. Concerns and confusion about tasks of a more ambiguous and authentic nature, paired with the difficulties of some to know basic mathematical terms and procedures, may have been mistaken for lack of ability.

Disciplinary connections to (and separations from) pedagogical views and teaching practices. Despite expressing several sophisticated and expert conceptions of statistics and statistical work, Mindy, Li and Sahil compartmentalized the nature of entry-level statistical work and higher-level work. The reason for this compartmentalization seems inextricably tied to the general pedagogical perceptions the participants expressed. In other words, Mindy, Li, and Sahil all discussed a substantive measure of flexibility in statistical work, at least some measure of open-endedness and ambiguity in the nature of statistical knowledge, and a socio-cultural and negotiated nature to the development of statistical knowledge. What they lacked was a learning theory that demonstrated why these facets of discipline should inform pedagogy.

In many ways, situated views of learning (Bruner, 1960/2009; Lave & Wenger, 1991) weave the world of disciplinary practices to the world of teaching. Situated views of learning argue that learners develop meaningful understanding by participating in the practices of practitioners and experts in the field, rather than merely learning *about* their work (Lave & Wenger, 1991). While Mindy's "learning by doing" motto of instruction would loosely relate to this perspective, situated learning goes farther by bringing attention to the tasks themselves. It is not enough to be engaged in tasks; students need *authentic* tasks.

Disciplinary compartmentalization contrasts with a situated view of learning in the belief that how *students* learn should not necessarily be informed by how *practitioners* engage in their work or even how the discipline has developed knowledge. But Bruner (1960/2009) would counter that argument by articulating that learning makes most sense when it emulates how experts have developed and constructed knowledge in the field.

> Mastery of the fundamental ideas of a field involves not only the grasping of general principles, but also the development of an attitude toward learning and inquiry…Just as a physicist has certain attitudes about the ultimate orderliness of nature and a conviction that order can be discovered, so a young physics student needs some working version of these attitudes if he is to organize this learning in such a way as to make what he learns usable and meaningful in his thinking (Bruner, p. 20).

All of the participants eventually adopted the notion that students needed to learn "the basics" before they would be able to engage meaningfully in contextually-based problems. Yet Bruner suggests that learning basic content soundly need not compete with learning and engaging in disciplinary practices. Jaber and Hammer (2016) add nuance to Bruner's message by highlighting the importance of affective response in disciplinary engagement. In describing the scientific learning of elementary students, the authors describe affective response as part of the "substance" students need when learning science and as a necessary component to motivate and structure learning experiences. Authentic experiences that excite students and acquaint them with the questions that disciplinary experts engage with can provide a platform for rich learning to take place (Engle & Conant, 2003).

Additionally, a constructivist view of learning provides important insights toward creating a meaningful instructional vision. Constructivism brings attention to how students think and develop conceptions of new ideas and processes (NRC, 2000). Tasks that foster opportunity for students to construct their knowledge into meaningful frameworks (rather than as an accumulation of facts for recall) are more open-ended, involve peer discussion, grant students more autonomy, and are comprised of more than finding right answers (Garfield & Ben-Zvi, 2009; Schoenfeld, 1992). Eliciting students' preconceptions, creating space for students to test ideas, and providing opportunity for students to reflect and synthesize on their thought-experiments represent key features of a constructivist learning environment (NRC, 2000).

To exemplify situated and constructed views of learning in the statistics classroom, statistics educators have recommended a number of instructional approaches. Informal inferential reasoning proposes that students approach statistical questions with their own ideas and informal approaches before being taught an algorithm or strict procedure (Gil & Ben-Zvi, 2011; Pfannkuch, 2011). This approach to learning engages students in the practices of statisticians who often adapt methods or create new methods to make sense of previously unexplored problems. Additionally, such tasks build on students' preconceptions to foster autonomy and flexible approaches. Secondly, exploratory data analysis is an important learning opportunity to demonstrate to students the importance of letting context and curiosity drive decisions and analysis (Cobb & Moore, 1997). Third, the use of computer simulations and other digital or physical tools can be leveraged strategically to allow students to explore their own questions and ideas as they make sense of important statistical concepts and phenomena (Chance et al., 2004; Chance & Rossman, 2006; Watson & Wright, 2008).

To different degrees, the participants expressed interest in and ascribed value to constructivist principles of learning by wanting to give more opportunities for students to participate in class rather than listen to lectures. However, the default practice-and-recall approach to teaching that emerged from these courses paid only lip service to constructivist principles. By viewing the content of introductory statistics as "the basics," it is not clear that the participants were ready to truly envision students constructing ideas somewhat informally, much less being able to exemplify the practices and dispositions of experts in such work.

The discussions above reflect important considerations for GTAs like Mindy, Li, and Sahil; these three already expressed several advanced perspectives about statistics. Kathy's was a different story, as her disciplinary views were already well aligned with an instructional vision focused on instrumental understanding. She had no reason to question this curricular and instructional approach. This approach was seemingly preparing students for the work of statistics, which she viewed as rather methodical, objective, and straightforward. Kathy's story demonstrates that disciplinary views that align with the true nature and the practices of the discipline are likely necessary; Li, Sahil, and Mindy's stories demonstrate that holding such views is probably necessary, but certainly not sufficient to exemplifying the reform-oriented instruction principles outlined in the GAISE Report.

A Vision for Future Research on Statistics GTA Professional Development

To conclude, I outline future work to be conducted in relation to the topics discussed in this dissertation. These implications for future research stem from my own findings while also informed by current research-based understandings of professional development. In particular, I make recommendations for future research that I believe will move the field forward regarding effective training of instructors and GTAs to teach introductory statistics courses.

Further development in surveying and understanding disciplinary views in statistics. Case study research does not allow for statistically-based generalizations to the population; it instead provides analytic generalizations rooted in the context of particular cases (Yin, 2009). My research contributes theory about the origin and implications of GTAs' disciplinary views, rooted in the specific context of my four cases. Thus, my findings offer insights into different perspectives GTAs articulate about statistics and how or whether these perspectives play a role in their instructional visions and teaching practices. More research is needed to understand how to better assess disciplinary views and refine the various sub-dimensions I proposed. Future work may draw from these findings (and other studies) to develop an instrument to assess the disciplinary perspectives of instructors, graduate students, or even introductory statistics students. Such an instrument could be used to assess the effectiveness of a statistics GTA training or professional development program with regard to providing authentic experiences and perspectives of the discipline. An instrument may also be useful to assess the views of students before and after a statistics course to see what impressions students are left with about the discipline as a result of a particular curriculum or instructional approach.

Future research may improve on my study by better parsing the various components of statistical knowledge and activity that were not clearly distinguished in my questioning. Viewing theorems, definitions, formulas, methods, and claims as distinct domains will no doubt prove more effective; as I found in my own data, the participants tended to take different perspectives depending on which facet of statistics we were discussing. Furthermore, the inclusion of only four participants of the same cohort at the same university suggests there are likely more perspectives and disciplinary tensions to be revealed.

Engaging statistics GTAs in disciplinary practices and conceptual ideas. Among the little literature available on the knowledge and experiences of statistics GTAs, there is a common theme that suggests many new GTAs struggle with conceptual tasks and lack learning experiences with introductory level content before teaching (Dolor, 2017; Green, 2010; Green & Blankenship, 2014; Justice et al., 2017; Noll, 2011). While this study did not specifically address the participants' content knowledge, it was clear that many of them had varied experiences with statistical content before beginning the program that no doubt reflected in differences in their content knowledge and curricular perspectives. Research with mathematics and science GTAs also reveals that their instructional visions are heavily borrowed and adapted from their own professors and often assume that class should exclusively revolve around lectures and practice problems (DeFranco & McGivney-Burrelle, 2001; Hammrich, 2001). Teaching conversations involving graduate students may easily fall back on differences in instructional styles, rather than more substantive instructional strategies. The enactment of more student-friendly teaching styles that boost student engagement were mistaken as being the essence of high-quality teaching (Gardner & Jones, 2011).

Highly effective statistics pedagogy engages students in disciplinary practices (Wild & Pfannkuch, 1999), pushes students to think deeply about concepts like sampling variation (Noll, 2011), prepares students to use statistical tools to model a situation (ASA, 2016), and orients students toward contextual meaning and decision-making that involve more than following given procedures (Pfannkuch, 2011). The GTAs in this dissertation likewise reflected various experiences to solve real-world problems. Mindy had opportunities to approach statistical questions with a great deal of flexibility, and this experience appeared central to her frustration with the emerging curricular goals of her introductory course. In contrast, Kathy had little experience solving statistical problems in a flexible manner, and she seemed quite content with a focus on procedures and computation. Based on the literature, coupled with findings from my dissertation, it would seem that GTAs may benefit from opportunities to grapple with interesting, open-ended problems that provide a basis for the true disciplinary nature of statistics. Future research may focus on designing such instructional experiences for GTAs to assess how their disciplinary views and conceptual understanding may develop as a result.

Supporting teaching practices aligned with statistical practices. Yet, as we saw with Mindy, Sahil, and Li, productive disciplinary perspectives were not enough to support instruction that facilitated authentic experiences for students (Speer, 2008). Fear of charting unknown instructional territory was a significant deterrent; even the feasibility of coordinating a class project was scary to some. Additionally, the avoidance of open-ended problems or rich, contextually-driven tasks may have also been a matter of disciplinary compartmentalization. As discussed in the findings, the GTAs generally ascribed the value of context in the classroom to engaging students, rather than any meaningful experience to thinking *within* context as an important problem-solving component (Wild & Pfannkuch, 1999). However, Mindy, Li, and Sahil all seemed to understand that context guides the decisions of statisticians and data scientists; they simply compartmentalized these practices from the nature of introductory statistics.

Future research is needed to investigate how a bridge can be constructed between GTAs' perceptions of advanced statistical practice and the work of students. One possible topic would be acquainting GTAs with tasks that engage introductory students in informal inferential reasoning and exploratory data analysis (Cobb & Moore, 1997; Gil & Ben-Zvi, 2011). We know from research, however, that providing instructors with high-quality instructional materials is often insufficient for changing practice (Ball & Cohen, 1999). Kaplan and Roland (2018) reported an initial resistance from statistics GTAs when they first began facilitating tasks that aligned more closely with recommendations from the GAISE Report. The participants in my dissertation study parallel these findings; failing to believe that students are capable of engaging productively in open-ended work is a hindrance toward enacting tasks that promote statistical literacy, thinking, and reasoning. Future research should assess GTAs' attitudes and perceptions of more open-ended tasks and assessments, paired with instruction on how to facilitate and grade such activities and assignments.

GTAs also need opportunity to see these tasks modeled effectively in the classroom, followed by time to reflect, discuss, and plan their use or adaption of such tasks in their own teaching. Future work is needed to study how to effectively incorporate reflections from classroom video, discussion of student thinking from written work, and reflection on instruction after administering such tasks (Borko & Koellner, 2008; Suzuka, Sleep, Ball, Bass, Lewis, & Thames, 2009; van Es & Sherin, 2002).

Finally, instructional preparation aligned with situated and constructed views of learning may have potential to solidify student-centered pedagogical views into a more cohesive pedagogical framework. Past studies document varying success engaging science GTAs in learning theories as part of their instructional training (Hammrich, 2001; Pentecost et al., 2012). Based on the disciplinary compartmentalization that took place among the participants in this dissertation study, there is reason to believe that immersion in situated and constructivist views of learning might motivate a clearer connection between the work of statisticians and data scientists to the work of students. Future work is needed to explore how the inclusion of learning theories in statistics GTA preparation may address disciplinary compartmentalization.

APPENDIX A

CONSENT FORMS, IRB APPROVALS, AND RECRUITMENT EMAILS

Final Consent Form

The Teaching Beliefs and Self-Efficacy of Incoming Statistics TAs

You are invited to participate in a research study on the beliefs and self-efficacy of incoming statistics TAs as it pertains to teaching introductory courses. You have been asked to participate because you are a new TA to the statistics program. I ask that you read this form and ask any questions you may have before agreeing to be in the study.

This study is being conducted by Kelly Findley, doctoral student, Math and Statistics Education, School of Teacher Education, Florida State University.

Background Information

I am conducting a study to better understand statistics TAs' initial thoughts and feelings about teaching statistics. The results of this study could provide valuable insight into instructor preparation and professional development for statistics instructors. A grounded theory approach will be used to analyze the data.

Procedures

If you agree to participate, you will be asked to consent to the following:

- Consent to allowing your interviews to be used as data (anonymously) for Kelly Findley's dissertation.
- Consent to allowing Kelly Findley to video record your teaching or access your course website as a student or teaching assistant.
- Consent to asking students who come in for office hour help for permission to audio record your sessions and take a picture of related written work. If the student is willing, and you are satisfied with the interaction, you may share this with Kelly.
- Consent to forwarding student de-identified email correspondence with Kelly when you deem these interactions to be centered around course content. You again make the decision to share these if you deem them appropriate and helpful to share.

Risks and benefits of being in the Study:

Your consent to sharing data for Kelly Findley's dissertation has no additional foreseeable risks. Artifacts from the data (e.g. interview video files and any work done on paper, field notes or personal notes from your teaching, video files of your teaching, audio files from your office hour interactions, and email correspondence you have with students over content that you choose to share) will be accessible to Kelly, but all data will be de-identified and reported in his dissertation in such a way that protects you from being identified. Benefits include your participation in improving the department program for TA training and contributing to research in the broader education community about new statistics TAs' beliefs and self-efficacy

Compensation

Participants will receive no compensation for consent.

Confidentiality

The data collected as part of this study will be kept private and confidential to the extent permitted by law. In any sort of report I might publish, I will not include any information that will make it possible to identify you or other individuals in the study. Research records will be stored securely on a password-protected computers and only the primary researcher and faculty advisors will have access. In the unusual circumstance that any sensitive information is shared, the instructor may ask for some portion of the data to be deleted or to be given additional protection (i.e., password-protected file), in which case the primary researcher will comply with any additional security request within reason.

Voluntary Nature of the Study

If you decide to participate, you are free to dismiss yourself from the study at any time

Contacts and Questions

The researcher conducting this study is Kelly Findley. You may ask any question you have now.

If you have a question later, you are encouraged to contact him at [redacted]

The faculty advisors of this study are Ian Whitacre and Elizabeth Jakubowski. If you would like to contact them with any questions, you may contact them at [redacted]

If you have any questions or concerns regarding this study and would like to talk to someone other than the researchers, you are encouraged to contact the FSU IRB at 2100 Levy Street, Research Building B, Suite 276, Tallahassee, FL 32306-2742 or 850-644-7900, or by email at humansubjects@fsu.edu.

You will be given a copy of this information to keep for your records.

Statement of Consent

I have read the above information. If necessary, I have asked questions and have received answers. *PLEASE INITIAL*

_____ I Consent to allowing my interview video files and work on paper to be used as data (anonymously) for Kelly Findley's dissertation.

_____ I Consent to allowing Kelly Findley to video record some of my classes or access my course website as a student or teaching assistant.

_____ I Consent to allowing Kelly Findley to have access to documented office hour interactions or email exchanges that I have chosen to share.

_____ I decline participation in this study

____ ____________
Signature of Participant Date

____ ____________
Signature of Investigator Date

Institutional Review Board Approval Letters

Florida State UNIVERSITY

Office of the Vice President for Research
Human Subjects Committee
Tallahassee, Florida 32306-2742
(850) 644-8673 · FAX (850) 644-4392

APPROVAL MEMORANDUM

Date: 07/27/2017

To: Kelly Findley [redacted]

Address: [redacted]

Dept.: CURRICULM AND INSTRUCTION

From: Thomas L. Jacobson, Chair

Re: Use of Human Subjects in Research
The Teaching Beliefs and Self-Efficacy Incoming Statistics TAs

The application that you submitted to this office in regard to the use of human subjects in the proposal referenced above have been reviewed by the Secretary, the Chair, and two members of the Human Subjects Committee. Your project is determined to be Expedited per 45 CFR § 46.110(7) and has been approved by an expedited review process.

The Human Subjects Committee has not evaluated your proposal for scientific merit, except to weigh the risk to the human participants and the aspects of the proposal related to potential risk and benefit. This approval does not replace any departmental or other approvals, which may be required.

If you submitted a proposed consent form with your application, the approved stamped consent form is attached to this approval notice. Only the stamped version of the consent form may be used in recruiting research subjects.

If the project has not been completed by 07/26/2018 you must request a renewal of approval for continuation of the project. As a courtesy, a renewal notice will be sent to you prior to your expiration date; however, it is your responsibility as the Principal Investigator to timely request renewal of your approval from the Committee.

You are advised that any change in protocol for this project must be reviewed and approved by the Committee prior to implementation of the proposed change in the protocol. A protocol change/amendment form is required to be submitted for approval by the Committee. In addition, federal regulations require that the Principal Investigator promptly report, in writing any unanticipated problems or adverse events involving risks to research subjects or others.

By copy of this memorandum, the chairman of your department and/or your major professor is reminded that he/she is responsible for being informed concerning research projects involving human subjects in the department, and should review protocols as often as needed to insure that the project is being conducted in compliance with our institution and with DHHS regulations.

This institution has an Assurance on file with the Office for Human Research Protection. The Assurance Number is IRB00000446.

Cc: Ian Whitacre [redacted]
HSC No. 2017.21031

The Florida State University
Office of the Vice President For Research
Human Subjects Committee
Tallahassee, Florida 32306-2742
(850) 644-8673, FAX (850) 644-4392

RE-APPROVAL MEMORANDUM

Date: 5/11/2018

To: Kelly Findley [redacted]

Address: [redacted]
Dept.: CURRICULM AND INSTRUCTION

From: Thomas L. Jacobson, Chair

Re: Re-approval of Use of Human subjects in Research
The Teaching Beliefs and Self-Efficacy Incoming Statistics TAs

Your request to continue the research project listed above involving human subjects has been approved by the Human Subjects Committee. If your project has not been completed by 5/9/2019, you must request renewed approval by the Committee.

If you submitted a proposed consent form with your renewal request, the approved stamped consent form is attached to this re-approval notice. Only the stamped version of the consent form may be used in recruiting of research subjects. You are reminded that any change in protocol for this project must be reviewed and approved by the Committee prior to implementation of the proposed change in the protocol. A protocol change/amendment form is required to be submitted for approval by the Committee. In addition, federal regulations require that the Principal Investigator promptly report in writing, any unanticipated problems or adverse events involving risks to research subjects or others.

By copy of this memorandum, the Chair of your department and/or your major professor are reminded of their responsibility for being informed concerning research projects involving human subjects in their department. They are advised to review the protocols as often as necessary to insure that the project is being conducted in compliance with our institution and with DHHS regulations.

Cc: [redacted]
HSC No. 2018.23885

Email Invitation to Participate in First Survey

Hi [name]

First, I want to say welcome to FSU statistics and congratulations on your assistantship!

My name is Kelly Findley, and I'm a former statistics TA here at FSU. I'm currently a PhD student in Mathematics Education and doing research on statistics TAs' experiences. I'm working with [the GTA Coordinator] this year on updating the department training, and we would love to learn more about our new TAs.

If you have an interest in solo teaching at some point while you are here (even if you're not sure yet), we would love for you to **complete this survey this week**. [survey link]

Your assigned ID number is **[X]**, so please fill that in the start box. I am the only one who will be able to link ID numbers to individuals. [the GTA Coordinator] will only see responses with the ID numbers, so she won't be able to match you with your responses. Your responses will in **no way** affect your consideration for a solo assignment. Your responses will simply help us learn more about all of you and provide better support and training for our new group of TAs.

Please let me know if you have any questions!

Email Invitation to Participate in First Interview

Hi again, [Name],

As part of my dissertation work, I'm also looking for new statistics TAs who would be willing to complete a short interview (about 20-25 minutes) to gather some richer data and learn more about everyone's background. Having an interview is completely optional and up to you. :) We could meet in person and I'll buy you a Starbucks drink, or we could meet over skype or google hangout if that is preferable for you.

The interview won't include any sensitive questions, but I would still like you to know that all your responses would be kept confidential, even from [the GTA Coordinator]. I can tell you more about my dissertation at the interview and how I would use the data.

Let me know if you would be open to completing an interview!

Email Invitation to Participate in Second Interview

Hi [Name]

Wanted to check in to see how your semester is going. Can I buy you a cup of coffee or tea this week and we can chat about your first semester experiences so far as part of my continuing dissertation work?

As with the first interview, this is completely voluntary and up to you. Please see the attached form to see details about how anything you say or share with me will be kept confidential.

If you would be up for meeting, let me know what times work for you!

Email Invitation to Participate in Third Interview

Hi [Name]

Wanted to check in to see how your semester is going. Can I buy you a cup of coffee or tea this week and we can chat about your second semester experiences and reflections on the teaching workshop? Again, this is part of my ongoing dissertation work.

If we meet, we can also talk about the final stage of my dissertation work, which involves observing some of the TAs teaching over the summer for the first time and continuing follow-up interviews about their experiences and instructional choices. I was wondering if you would like to participate in that. We can talk about that if you're interested in continuing along with that!

Note that at the conclusion of interview 3, all participants signed the consent form in its final version. Formal requests for interview were no longer needed.

Email Notification for Students in Courses to be Video Recorded

[First video observation:]

[Fill in typical instructor greeting]

I wanted to let you know that a doctoral student from the department of Math Education, Kelly Findley, will be video recording our class tomorrow. This observation is part of his study of graduate student instructors like me to learn more about how I teach and understand my role as an introductory statistics instructor. His research will not include any analysis of students, so nothing you say during class tomorrow will be used for any purpose. Kelly will not share any part of this video with anyone else.

Please view tomorrow as a normal class, and don't be afraid to speak and ask questions in class like you would normally. If you would prefer not to be in the camera's view, please let me know at the beginning of class so I can let you know which seats will be in the camera's line of vision.

Thanks, and let me know if you have any questions or concerns!

[Following observations made]

[Fill in typical instructor greeting]

Kelly will be video recording tomorrow. Keep that in mind as you take your seats if you don't want to be in the camera's view.

Thanks, and let me know if you have any questions!

APPENDIX B

SURVEYS

Survey 1

Please rate the extent to which you agree with the following statements about instruction in introductory statistics courses for non-majors.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Most students learn best when they try statistical problems using their own ideas before learning formal methods (like t-tests and Chi-Square tests).					
Most students learn more from a good lecture than they do from a good activity.					
Most students learn best when they use simulations (a web page or software application with interactive scales/buttons) to learn difficult concepts.					
Students should occasionally work with *messy* datasets (missing data, outliers, and/or messy formatting).					
Students should get quizzes or tests back with written feedback to improve their learning.					
Student grades should be determined primarily by individually completed homework, quizzes, or exams.					
Students grades should be determined primarily by projects, presentations, or group assignments/activities.					
Questions using made-up data are just as effective as questions using real data, just as long as students aren't misled to believe it's real.					
Most students should learn more topics in less detail instead of fewer topics in more detail.					
Students should learn how to use software beyond calculators (like Excel or R) to do basic statistical analysis.					
Students should develop a deep understanding of sampling distributions.					
The course should spend at least one class period covering rules of probability (like the multiplication rule, conditional probability formula, or adding disjoint events).					
The course should familiarize students with the binomial probability mass function (pmf).					
The course should familiarize students with the normal probability density function (pdf).					
It is important for students to see and learn about statistical formulas (like the formula for standard deviation).					

The course should require students to make calculations using formulas (by hand or with calculator).					
Students do not need to learn the mathematics behind statistical methods as long as they can use the methods properly and interpret results correctly.					
Students should learn how to write statistical questions.					
Students should learn how to outline a statistical study, including a plan for data collection and analysis.					
Students should complete a statistical project in the course.					
Students should learn how to write up a report describing a study from start to finish.					
Students should learn to carefully judge and evaluate data-based arguments and claims they see in the media.					

Consider the total amount of in-class time you have as an instructor for the entire semester. What percentage of class-time would you like to spend for each of these things? Percentages should add up to 100%

a) Lecture, teacher demonstration, or teacher answering student questions:

b) Activities completed in small groups, students discussing with students, group quizzes:

c) Students working on problems independently:

d) Individually completed exams/quizzes:

e) Other (like student presentations, showing videos, clicker questions, etc.):

Indicate the method of computing numerical solutions to problems that you believe helps students learn statistics best.

a) All solutions computed by hand

b) Most solutions computed by hand

c) Equal amounts of computing solutions by hand and using technology tools

d) Most solutions computed using technology tools

e) All solutions computed using technology tools

Survey 2

Please rate the extent to which you agree with the following statements about instruction in introductory statistics courses for non-majors. Keep in mind, these are your beliefs about an *ideal* introductory course, not necessarily how your own course went this past semester.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Most students learn best when they try statistical problems using their own ideas before learning formal methods (like t-tests and Chi-Square tests).					
Most students learn more from a good lecture than they do from a good activity.					
Most students learn best when they use simulations (a web page or software application with interactive scales/buttons) to learn difficult concepts.					
Students should occasionally work with *messy* datasets (missing data, outliers, and/or messy formatting).					
Students should get quizzes or tests back with written feedback to improve their learning.					
Student grades should be determined primarily by individually completed homework, quizzes, or exams.					
Students grades should be determined primarily by projects, presentations, or group assignments/activities.					
Questions using made-up data are just as effective as questions using real data, just as long as students aren't misled to believe it's real.					
Most students should learn more topics in less detail instead of fewer topics in more detail.					
Students should learn how to use software beyond calculators (like Excel or R) to do basic statistical analysis.					
Students should develop a deep understanding of sampling distributions.					
The course should spend at least one class period covering rules of probability (like the multiplication rule, conditional probability formula, or adding disjoint events).					
The course should familiarize students with the binomial probability mass function (pmf).					
The course should familiarize students with the normal probability density function (pdf).					
It is important for students to see and learn about statistical formulas (like the formula for standard deviation).					
The course should require students to make calculations using formulas (by hand or with calculator).					

Students do not need to learn the mathematics behind statistical methods as long as they can use the methods properly and interpret results correctly.					
Students should learn how to write statistical questions.					
Students should learn how to outline a statistical study, including a plan for data collection and analysis.					
Students should complete a statistical project in the course.					
Students should learn how to write up a report describing a study from start to finish.					
Students should learn to carefully judge and evaluate data-based arguments and claims they see in the media.					

Consider this past semester of teaching. Rate the extent you agree or disagree with each statement in terms of what you feel actually happened.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Students had opportunities to try statistical problems using their own ideas before learning formal methods (like t-tests and Chi-Square tests).					
Students used simulations (a web page or software application with interactive scales/buttons) to learn difficult concepts.					
Students worked with *messy* datasets (missing data, outliers, and/or messy formatting).					
Students got quizzes or tests back with written feedback to improve their learning.					
Students learned more topics in less detail instead of fewer topics in more detail.					
Students learned to use software beyond calculators (like Excel or R) to do basic statistical analysis.					
Students developed a deep understanding of sampling distributions.					
Students saw and learned about statistical formulas (like the formula for standard deviation).					
Students regularly made calculations using formulas (by hand or with calculator).					
Students learned how to write statistical questions.					
Students learned how to outline a statistical study, including a plan for data collection and analysis.					

Students learned how to write up a report describing a study from start to finish.					
Students learned how to carefully judge and evaluate data-based arguments and claims they see in the media.					

Rank each of these three potential aims for an introductory course as you feel they should be emphasized in an introductory statistics course.

a) Students should learn applied methods to be able to complete statistical investigations

b) Students should learn the foundations of statistics and the mathematics behind methods

c) Students should learn to carefully judge and evaluate data-based arguments and claims they see in the media

Thinking about your own class this past semester, how do you think these aims were actually most emphasized? Rank them in the order you believe they were emphasized.

a) Students should learn applied methods to be able to complete statistical investigations

b) Students should learn the foundations of statistics and the mathematics behind methods

c) Students should learn to carefully judge and evaluate data-based arguments and claims they see in the media

Consider the total amount of in-class time you have as an instructor for the entire semester. What percentage of class-time would you like to spend for each of these things? Percentages should add up to 100%

a) Lecture, teacher demonstration, or teacher answering student questions:

b) Activities completed in small groups, students discussing with students, group quizzes:

c) Students working on problems independently:

d) Individually completed exams/quizzes:

e) Other (like student presentations, showing videos, clicker questions, etc.):

Thinking about your own class this past semester, how much class-time would you say was actually spent on each of these components? Percentages should add up to 100%

a) Lecture, teacher demonstration, or teacher answering student questions:

b) Activities completed in small groups, students discussing with students, group quizzes:

c) Students working on problems independently:

d) Individually completed exams/quizzes:

e) Other (like student presentations, showing videos, clicker questions, etc.):

Indicate the method of computing numerical solutions to problems that you believe helps students learn statistics best.

a) All solutions computed by hand

b) Most solutions computed by hand

c) Equal amounts of computing solutions by hand and using technology tools

d) Most solutions computed using technology tools

e) All solutions computed using technology tools

Thinking about your own class this past semester, which best describes how students computed numerical solutions?

a) All solutions computed by hand

b) Most solutions computed by hand

c) Equal amounts of computing solutions by hand and using technology tools

d) Most solutions computed using technology tools

e) All solutions computed using technology tools

APPENDIX C

INTERVIEW PROTOCOLS

Interview 1 [September, Year 1]

Interview Questions

- What degree programs were you a part of before entering this program?
- Do you have any teaching experience? Tutoring experience?
    - Did you enjoy teaching/tutoring? What was enjoyable? What was difficult? If you taught, tell me about a typical class period.
- What statistics coursework if any have you had up till now?
- Tell me about the previous statistics (or mathematics) teachers you have had.
    - Tell me about how they taught. (how much did they lecture? How much did students ask questions and engage in class discussions? Did you complete any activities in class? What was homework like? Did you do any tests or projects?)
    - What did you like and what did you dislike?
- Tell me about the kind of teacher you will be. How will you be similar or different than the teachers you have had before?
    - How do you describe the role of an instructor in an introductory statistics course? How is a stats instructor different from a math instructor?
- How would you define statistics?
    - (another way to ask): How would you define the field of statistics to someone who doesn't know much about statistics?
    - I will then ask each GTA to compare the following two definitions of statistics and tell me what they think of each definition (do you agree with one more than another?) and whether that helps them think of their own definition:
        1) Statistics is a collection of mathematical methods, algorithms, and procedures based on applications of probability to model real-world situations.
        2) Statistics is the scientific process of using mathematical methods to pose questions, collect data, analyze data, interpret data, and report findings.
- What do you think it means to do statistics?
    - (another way to ask): What kinds of tasks do you think a statistician or a data scientist does?
    - What about a non-statistician who uses statistics for their job. What kinds of tasks might they do?
- Why should undergraduate students in a non-mathematical/statistical major take an introductory statistics course? What should they learn?
    - I might potentially follow up by presenting the following two answers and asking for their thoughts:
        1) Students should learn about different probability distributions (binomial, normal, chi-squared) and complete calculations fluently.

2) Students should learn how to conduct research that involves using statistics

- Read the following statements. How would you rank these potential course goals in order of importance for introductory statistics students?
  1) Students should learn to carefully judge and evaluate data-based arguments and claims they see in the media.
  2) Students should learn applied methods to be able to complete statistical investigations
  3) Students should learn the foundations of statistics and the mathematics behind methods

Interview 2 [November, Year 1]

Interview Questions

- Tell me about your graduate classes.
  - How are they going?
  - What are you learning about?
  - Which class is hardest and why?
- Tell me about your interactions with others in the department
  - Do you ever have informal and unplanned discussions with other graduate students, lecturers, or faculty members to discuss topics related to teaching or assisting courses?
    - With who?
    - How frequently?
    - What kinds of things do you discuss?
- How do you feel about your recitation duties?
  - How do you facilitate your activities?
  - How familiar is the content to you? Do the questions and tasks look similar to things you've seen in your own classes?
  - Any interesting or unexpected events happen so far in your recitation duties?
  - Do you like being a recitation instructor? (reminder that this interview is confidential and they can speak freely to me)
  - If you were Radha, is there anything you would do differently?

Statistics Mind Map Task

1) When you think about "statistics," what words, terms, or phrases come to mind?
   a. Create a word wall of any term, phrase, or idea you associate with a statistics course and doing statistics
   b. Try to list at least 20 things!
2) Are you able to categorize any of these words/terms/phrases together? (like apples, bananas, and pears would be subsets of fruit)
   a. Create a mind map that organizes these terms, then we might use an online mind map tool to clean it up
3) Which of these ideas and skills would you consider central to what statistics is? Which are less central?

Interview 3 [March, Year 1]

Interview Questions

- Tell me about this semester so far
    - How are your classes going? What's been the hardest class? Your favorite class?
    - How have your recitation duties been going?
- Tell me about the workshop
    - What are the activities and assignments you completed that were the most helpful?
        - Review their post-workshop evaluation and discuss their scores to different segments.
- Let's follow up on your survey results to see if anything changed from the first time you took it
    - Do you feel significantly different about this item now than you did before?
    - What caused that change for you?"
- Tell me about the classroom visits you made.
    - What do you remember about X's classroom?
    - What did you like? What did you dislike?
    - How do you imagine your classroom and instruction being similar or different?
        - How would you describe your role as a teacher (solo instructor)?
        - How do students learn statistics best?

Disciplinary Dimension Questions

The Nature of Statistics

- Is there an advantage to statistics being its own department, as opposed to statistics being embedded in mathematics departments?
    - As far as statistical research is concerned, do you think it matters whether statisticians are in their own department, or working out of a mathematics or mathematical science department?
    - What distinguishes a statistical problem from a mathematical problem?
        - If I gave you a list of 10 questions, half being from mathematics department courses and half from statistics department courses, would you be able to sort out which questions came from where? How?
        - Can you draw a Venn Diagram with one circle representing mathematics and one representing statistics? How much should they overlap? What things should be in each sector?

The Nature of Statistical Knowledge

- [I will display the formula for standard deviation] What do you think about the formula for standard deviation and its construction? What is going on in this formula? [reassurance that this is not an assessment, that it's ok to be unsure]
    - How would you react to reading a peer-reviewed research paper that used absolute deviations instead of squared deviations in the formula?
        - Do you think there is a context where that alteration could be ok, or is that wrong?

        - Do you think all statisticians agree on the current formula we see in textbooks today?
    - Statistics research has traditionally been pushed forward by researchers in the United States and in the West. If something happened and the United States no longer had capacity to lead research, do you think having another culture (say the Far East like China and Japan) taking the lead in the progress of the discipline would change any of the conventions we use, our source of methods, or nature of future methods?

The Nature of Knowing Statistics

- Would you say research in statistics is mainly an individual or a collective process?
    - If I prove something in my office or refine a new method, is it statistical knowledge right away, or does it need to be read, evaluated, negotiated, criticized, published, and taken up before we could consider it statistical knowledge?
    - Some claim that statistical knowledge is discoverable truth, yet others argue that such knowledge is invented or constructed by our minds. What is your opinion about this?
    - What role does proof play in the development of statistical knowledge and methodology?
        - Is there a difference between the nature of mathematical proofs and statistical proofs?
        - Do statistical proofs require assumptions? When you think about what it means to prove something in statistics, do you think it matters if proofs and methodologies require certain assumptions and conditions?

The Nature of Doing Statistics

- What are the different ways people participate in the discipline of statistics? [Possible ideas to probe: within research for statistics journals, data science, carrying out research methods, student/statistical literacy, teaching]
    - Some hold that solving problems in statistics is a thinking activity involving personal creativity. Others argue that solving these problems require following predetermined, known procedures. What is your opinion about this?
        - Do you think that solving statistical problems is an objective or subjective process, or somewhere in between? Can you explain/provide examples?
    - Do you think that data is objective?
    - Do you think statistics is related to art? Why or why not?

Pedagogical Questions

- Can someone at the level of your introductory students participate in statistics?
    - What might you reasonably expect of them after taking an intro course?
    - How will what they do in your intro course prepare them for these roles?
- What are the characteristics of someone who is knowledgeable in statistics?
    - Can you think of the different kinds of ways someone can be knowledgeable in statistics? Including outside the traditional statistics degree track?

- Can someone at the level of your introductory students be knowledgeable in statistics? If so, how?
- How can intro students become knowledgeable in statistics?
    - After initial thoughts, list ideas: Listening, working problems, discussing and collaborating with others on projects, evaluation of peer work or ideas, questioning conventions or established methods, doing projects independently, writing and reflecting, reading, working under a supervisor on statistical project?
- What role do you as the instructor play in helping your students become knowledgeable?
    - After initial thoughts, list ideas: Lectures, working practice problems, posting important things on course site (what things?), promoting discussion, writing and/or reflection assignments, solo or group projects, examinations, activities, assigning things to read, posing difficult problems, having students explore/analyze messy datasets?

Interview 4 [Beginning of first solo teaching semester]

Interview Questions

- Tell me how your course planning went.
    - What resources or experiences did you consult as you were planning?
        - Did you consult the textbook?
        - Did you consult online resources?
        - Did you consult people (Radha, classmates, professors)?
    - Do you feel like you learned anything new about statistics or that your understanding of statistics was enriched?
        - From the workshop?
        - From preparing specifically for your course?
    - Do you see the introductory course you teach and the graduate courses you take as portraying similar perspectives of statistics, or do you see them representing different perspectives?
- Tell me about your plan for teaching.
    - Tell me about [X] in your syllabus, why did you decide to structure/manage your class this way?
    - In a typical class period, how do you plan to piece out your time? Lecturing (writing on the whiteboard, using doc cam? etc.), activities, individuals working on problems, other things?
        - Are these different than the breakdown you had on the previous survey?
        - Tell me why you feel this breakdown will be best (Student learning? Instructor convenience? Other thoughts?)

Course Objectives/Learning Goals Task

For this task, I want to capture GTAs' philosophy regarding the aims of the intro course and how that might connect to their conceptualization of statistics. This task will also connect GTAs' philosophy with their curricular knowledge by laying out their vision for the progression of the course.

[So to start, I will ask GTAs the following]

1) Think about what you want students to learn and be able to do by the end of your course. Create a list of potential learning objectives (skills, understandings, kinds of questions they should be able to answer, ways of looking at the world differently, etc.)
2) Describe the progression of your course in a general timeline. What do you see as the big ideas in your course?
   [I expect GTAs to gravitate to a list of topics (how the GTA supervisor generally breaks down the course they served as GTAs for). I'm curious whether they see their course in terms of a progression of ideas, or if they see it as a list of seemingly disjoint topics. The following questions will probe which of those perspectives they seem to hold, regardless of how they initially answer this question]
3) Does the ordering matter? Do you see any of these topics building on one another?
4) Are there certain key ideas or themes that stream through multiple topics? Are there any foundational ideas that you see your course building from?

[After this initial brainstorm, I will then present them with the following list of potential objectives on individual slips of paper on the table]

5) Consider the following list of objectives:

   - Students should become critical consumers of statistically-based results reported in popular media, recognizing whether reported results reasonably follow from the study and analysis conducted.
   - Students should develop a deep understanding and appreciation for the mathematics behind statistical methods.
   - Students should view statistics as a process of posing questions, collecting data, analyzing data, and drawing inferences about the population.
   - Students should develop a deeper awareness of variability and the implications on everyday life.
   - Students should recognize and be able to explain the role of randomness in designing studies and drawing conclusions.
   - Students should recognize the close link between probability and statistical inference.
   - Students should learn about basic probability and distribution theory, including foundational rules and probabilistic notation.
   - Students should gain experience with using and understanding statistical models.
   - Students should demonstrate an awareness of *ethical issues* associated with sound statistical practice.

   There are 9 objectives listed here, but let's say you could have only 8 on your syllabus. Which one would you eliminate?

   [I will continue this process (you can only have 6, 5, etc.) until GTAs have essentially ranked all course objectives from least crucial to most crucial to their syllabus. I will ask for them to comment on each elimination.]

6) Now consider the following potential learning goals for your course. Categorize each learning goal as 1, 2, or 3 where 1 means it is minimally important, 2 means it is moderately important, and 3 means it is absolutely important

    - Students should be able to recognize and write questions that can be answered using statistics
    - Students should learn different methods of sampling
    - Students should be able to produce graphical displays by hand or with a calculator
    - Students should be able to produce graphical displays using computer software
    - Students should be able to solve problems involving conditional probability
    - Students should learn to solve problems involving the binomial probability mass function
    - Students should learn how to complete problems that involve finding areas under a normal curve
    - Students should develop a deep understanding of sampling distributions
    - Students should be able to complete statistical tests by hand using statistical tables
    - Students should be able to complete statistical tests on their calculators
    - Students should be able to complete statistical tests using computer software (either coding or with "point and click")
    - Students should be able to write elementary code using statistical software
    - Students should be able to interpret and draw conclusions from standard output from statistical software packages.
    - Students should collect data (either in real life or using an online virtual tool) in the course to analyze for a project or homework assignment
    - Students should complete a full study that includes 1) posing questions, 2) collecting Data, 3) analyzing data, and 4) drawing conclusions
    - Students should learn how to write a statistical report outlining a full study.
    - Students should learn to critique and evaluate a study's claims based on the research design (e.g., sample size, assumptions, causation vs. correlation, etc.)

[I plan to print each goal out on a piece of paper so they can sort them in three places on the table. From here, I plan to have them create a bit more of a hierarchy within each category as well to see if they can further distinguish which are prioritized]

7) How do you see the objectives and learning goals you picked as most important connecting with your progression? How will this progression enable students to attain these objectives and goals?
8) Is there anything that you are particularly worried about teaching? What do you think will be difficult for you to teach and why?

Interview 5 [Middle of first solo teaching semester]

Interview Questions

- Tell me about your course so far

- What words would you use to describe teaching your own stats course?
    - Frustrating, Enjoyable, Challenging, Time-consuming, Fulfilling, Annoying, Easy, Unimportant, Scary, or something else?
- Have there been any surprises or unexpected problems?
- Do you think you teach and manage your class the way you expected to before the semester began?
- In general, can you tell me:
    - What has gone well?
    - What has not gone well?
    - Do you feel your teaching is well aligned with the goals and objectives you privileged from the activity we did in the last interview?

- Let me get your opinion on the classes I observed you teach
    - What percentage of the class would you say you lectured, facilitated activities/discussion, facilitated individual work, or something else? Is that typical?
    - Tell me more about [specific moment I describe]. What was your motivation to respond in that way?
    - Tell me more about [specific quiz/task/homework/assessment item]. What was the goal of this [item/assignment/etc.]

Interview 6 [End of first solo teaching semester]

Interview Questions

- Let's look at your survey responses
    - First let's compare your ideal to your actual
    - Now let's look at any changes between initial, pre teaching, and post teaching
    - What do you think inspired these changes?
- [Questions connecting disciplinary views from previous interviews and certain instructional decisions I noticed]
- [Questions connecting expressed pedagogical views from previous interviews and certain instructional decisions I noticed]
- Let me get your opinion on the classes I observed you teach.
    - How much do you think you spent in these different instructional modes?
    - Let's look at what actually happened. Is this surprising or about what you would expect?
    - Tell me more about [specific moment I describe]. What was your motivation to respond in that way?
    - Tell me more about [specific quiz/task/homework/assessment item]. What was the goal of this [item/assignment/etc.]?
- Tell me about the next time you teach.
    - Is there anything you would change?
    - If you could tell yourself something when you started, what would you say?
    - What was the hardest thing about teaching?
- Let's follow up on your survey results to see if anything changed from the last time
    - Do you feel significantly different about this item now than you did before?
    - Did anything change from last time?

APPENDIX D

TASK CODING FRAMEWORK

Flexibility and Openness

Level	Description
0	The task only asks students for specific answers that involve little to no flexibility in approach - Task is almost entirely characterized by procedural work. For example: recalling definitions of terms or symbols, reporting numbers/counts from a table or graph, providing answers from the notes in a fill-in-the-blank format, or completing calculations or steps following prescribed procedures
1	The task is predominately looking for specific answers, and the solution path largely requires following specific procedures or using specific phrases (as described in Level 0), but there are isolated questions (10-30%) that may allow for open-ended responses, even if there may be a particular phrasing or procedure in the notes that could be used
2	Code at level 2 when the situation described in level 1 is found frequently in the task (more than 30%) OR if there are isolated questions (10-30%) that ask students for more open-ended responses that require more than a phrase or fill-in-the-blank template answer - Focus on interpretation in context that requires clear digging in and reflection (writing more than a phrase, or fill-in-the-blank template is not provided in the notes) - There may be more than one valid answer - Students are positioned to construct a method to solve the problem - Students are positioned to be decision-makers in a meaningful way
3	The task allows for extended opportunities (more than 30%) for open-ended responses (as described in the bullet points for level 2) for which there is not a specific phrasing or procedure to apply

Contextual Integration

Level	Description
0	The task involves no contextual example
1	The task involves context that is unclear OR the context does not affect how students engage in the task - For example, the variable names could easily be interchanged with other variable names, but the answers and solution paths would be the same)
2	The task involves context that is both clear and pushes students to think about contextual implications beyond simple fill-in-the-blank or short answer conclusions - The task pushes students to think about an issue - Students are making decisions about what to do based in the context - The context influences how students approach the task or answer the questions
3	The task matches the characteristics of level 2 + includes opportunities for students to discuss the context, explore the data visually, or approach the problem differently by responding to the particular contextual needs

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

Thompson, C. L., & Zeuli, J. S. (1999). The frame and the tapestry: Standards-based reform and professional development. In Darling-Hammond, L. & Sykes, G. (Eds.), *Teaching as the Learning Profession: Handbook of Policy and Practice* (pp. 341-375). San Francisco, CA: Jossey-Bass.

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Woods, T. (2016). 'Mathwashing,' Facebook and the zeitgeist of data worship. *Technically Brooklyn*. https://technical.ly/brooklyn/2016/06/08/fred-benenson-mathwashing-facebook-data-worship/ February 16, 2018.

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Zieffler, A., Park, J., Garfield, J., delMas, R., & Bjornsdottir, A. (2012). The statistics teaching inventory: A survey on statistics teachers' classroom practices and beliefs. *Journal of Statistics Education*, *20*(1), 1-2

BIOGRAPHICAL SKETCH

Kelly P. Findley

Curriculum Vitae

EDUCATION

2015-2019 **Ph.D. Curriculum & Instruction: Mathematics Education**
Florida State University, Tallahassee, FL
Supervisors: Elizabeth Jakubowski & Ian Whitacre.

Findley, K. (2019). *Connecting disciplinary and pedagogical spaces in statistics: Perspectives from graduate teaching assistants*. Unpublished doctoral dissertation, Florida State University.

2013-2015 **M.S. Statistics**
Florida State University, Tallahassee, FL

2009-2013 **B.A. Mathematics**
Bryan College, Dayton, TN
Minors: Politics & Government, Music

APPOINTMENTS

2018 – 2019 **Graduate Instructor**
School of Teacher Education
Florida State University

- Co-taught ISC3523: Research Methods as part of the FSU-Teach program for secondary mathematics and science teacher candidates
- Taught EDF1005: Introduction to Education for prospective teacher candidates

2015-2018 **Research Assistant**
Teaching and Learning Algebraic Thinking Across the Middle Grades: A Research-based Approach Using PhET Interactive Simulations *(NSF Grant #1503510)*
Florida State University

- Assisted with data collection by recording lessons, interviewing teachers, and helping teachers understand and use curricular materials
- Prepared and reviewed curricular materials used in the project
- Contributed to research efforts (e.g., analyzing data, giving presentation, writing papers)

2014-2015, 2017 **Graduate Instructor**
Department of Statistics
Florida State University

- Taught STA2171: Statistics for Biology and STA2122: Introduction to Applied Statistics
- Developed my own curricular materials and facilitated various group projects as part of these courses

2013-2014 **Graduate Teaching Assistant**
Department of Statistics
Florida State University

- Served as a teaching assistant for CGS2518: (Excel) Spreadsheets for Business
- Served as recitation instructor for STA2023: Fundamental Business Statistics
- Graded for STA4321: Introduction to Mathematical Statistics

COURSES TAUGHT

Florida State University

- EDF1005: Introduction to Education
- ISC3523: Research Methods
- STA2122: Introduction to Applied Statistics
- ST2171: Statistics for Biology

REFEREED JOURNAL ARTICLES

Findley, K. & Lyford, A., (in press). Investigating students' reasoning about sampling distributions through a resource perspective. *Statistics Education Research Journal*, *18*(1).

Findley, K., Whitacre, I., Schellinger, J., & Hensberry, K. K. R. (in press). Orchestrating mathematics lessons with interactive simulations: Exploring roles in the classroom. *Journal of Technology and Teacher Education*, *27*(1).

Whitacre, I., Hensberry, K. K. R.., Schellinger, J., & **Findley, K.** (2018). Variations on play with interactive computer simulations: Balancing competing priorities. *International Journal of Mathematical Education in Science and Technology*. doi.org/10.1080/0020739X.2018.1532536

Hensberry, K. K. R., Whitacre, I., **Findley, K.**, Schellinger, J., & Wheeler, M. B. (2018). Engaging students with mathematics through play. *Mathematics Teaching in the Middle School*, *24*(3), 179-183.

Whitacre, I., Atabas, S., & **Findley, K.** (2018). Exploring unfamiliar mathematical territory: Constraints and affordances in a preservice teacher's reasoning about fraction comparisons. *Journal of Mathematical Behavior*. doi.org/10.1016/j.jmathb.2018.06.006

Atabas, S., Schellinger, J., Whitacre, I., **Findley, K.**, & Hensberry, K. K. R. (under review). A tale of two sets of norms: Comparing opportunities for student agency in mathematics lessons with and without interactive simulations. *Journal of Mathematical Behavior.* Manuscript submitted for publication, 36 pages.

PROCEEDINGS

Findley, K. & Kaplan, J. J. (in press). Is statistics just math? The developing epistemic views of graduate teaching assistants. In A. Weinberg, C. Rasmussen, J. Rabin, M. Wawro, & S. Brown (Eds.), *22nd Annual Conference on Research in Undergraduate Mathematics Education.* Oklahoma City, OK.

Findley, K. & Atabas, S. (2018). Middle-schoolers' construction of probabilistic vocabulary. In T. E. Hodges, G. J. Roy, & A. M. Tyminski (Eds.), *Proceedings of the 40th annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education* (pp. 868-871). Greenville, SC.

Atabas S., **Findley, K.**, & Schellinger, J. (2018). Using interactive simulations to think mathematically and engage in cognitively demanding tasks. In T. E. Hodges, G. J. Roy, & A. M. Tyminski (Eds.), *Proceedings of the 40th annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education* (pp. 1091-1093). Greenville, SC.

Findley, K. & Kaplan, J. J. (2018). What is statistics? Examining the disciplinary beliefs of incoming statistics TAs. In M. A. Sorto, A. White, & L. Guyot (Eds.*), Looking back, looking forward. Proceedings of the Tenth International Conference on Teaching Statistics,* Kyoto, Japan.

Findley, K. & Kaplan, J. J. (2018). Cognitive resources in student reasoning about mean tendency. In A. Weinberg, C. Rasmussen, J. Rabin, M. Wawro, & S. Brown (Eds.), *21st Annual Conference on Research in Undergraduate Mathematics Education* (pp. 1345-1351). San Diego, CA.

Findley, K., Whitacre, I., & Hensberry, K. (2017). Integrating interactive simulations into the mathematics classroom: Supplementing, enhancing, or driving? In E. Galindo & J. Newton (Eds.), *Proceedings of the 39th annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education* (pp. 1297-1304). Indianapolis, IN.

Whitacre, I., Hensberry, K. & **Findley, K.** (2017). Teachers' facilitation of play with PhET interactive simulations in middle-school mathematics lessons. In E. Galindo & J. Newton (Eds.), *Proceedings of the 39th annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education* (pp. 1386). Indianapolis, IN.

Haider, M., Bouhjar, K., **Findley, K.**, Quea, R., Keegan, B., & Andrews-Larson, C. (2016). Using student reasoning to inform assessment development in linear algebra. In T. Fukawa-Connelly, N. E. Infante, M. Wawro, & S. Brown (Eds.), *19th Annual Conference on Research in Undergraduate Mathematics Education* (pp. 163-177). Pittsburgh, PA.

PRESENTATIONS

Refereed Presentations

Findley, K. & Kaplan, J. J. (February 2019). *Is statistics just math? The developing epistemic views of graduate teaching assistants*. Presentation at 22nd Annual Conference, Research in Undergraduate Mathematics Education (RUME), Oklahoma City, OK. (National)

Findley, K. & Kaplan, J. J. (January 2019). *Is statistics just math? The developing epistemic views of graduate teaching assistants*. Presentation at the Joint Mathematics Meetings (JMM), Baltimore, MD (National)

Findley, K. & Atabas, S. (November 2018). *Middle-schoolers' construction of probabilistic vocabulary*. Presentation at the 40th annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education (PME-NA), Greenville, SC. (International)

Atabas S. & **Findley, K.**, & Schellinger, J. (November 2018). *Using interactive simulations to think mathematically and engage in cognitively demanding tasks.* Presentation at the 40th annual meeting of the Psychology of Mathematics Education (PME-NA), Greenville, SC. (International)

Findley, K. & Kaplan, J. J. (July 2018). *What is statistics? Examining the disciplinary beliefs of incoming statistics TAs*. Presentation at 10th International Conference on the Teaching of Statistics (ICOTS), International Association of Statistics Education (IASE), Kyoto, Japan. (International)

Findley, K. (February 2018). *Cognitive resources in student reasoning about mean tendency*. Presentation at 21st Annual Conference, Research in Undergraduate Mathematics Education (RUME), San Diego, CA. (National)

Findley, K., Whitacre, I., & Hensberry, K. K. R. (October 2017). *Integrating interactive simulations into the mathematics classroom: Supplementing, enhancing, or driving?* Presentation at 39th Annual Conference, Psychology of Mathematics Education – North America (PME-NA), Indianapolis, IN. (International)

Whitacre, I., Hensberry, K. K. R., & **Findley, K.** (October 2017). *Teachers' facilitation of play with PhET interactive simulations in middle-school mathematics lessons*. Poster Presentation at 39th annual meeting, North American Chapter of the International Group for the Psychology of Mathematics Education (PME-NA), Indianapolis, IN. (International)

Whitacre, I., Hensberry, K. K. R., & **Findley, K.** (February 2017). *Examining the play phase of mathematics lessons involving computer simulations*. Presentation at 21st Annual Conference, Association of Mathematics Teacher Educators (AMTE), Orlando, FL. (National)

Hollingsworth, L., **Findley, K.**, & Jakubowski, E. (January 2017). *Do college level mathematics courses support student success in introductory statistics?* Presentation at Joint Mathematics Meetings (JMM), Mathematics Association of America (MAA), Atlanta, GA. (National)

Haider, M., Bouhjar, K., **Findley, K.**, Quea, R., & Andrews-Larson, C. (February 2016). *Using student reasoning to inform assessment development in linear algebra*. Presentation at 19th Annual Conference, Research in Undergraduate Mathematics Education (RUME), Pittsburgh, PA (National)

Nonrefereed Presentations

Findley, K. (May 2018). *The statistical epistemologies of first year graduate teaching assistants*. Presentation at Electronic Conference on Teaching Statistics (eCOTS) 2018 North Florida Regional Conference, Consortium for the Advancement of Undergraduate Statistics Education (CAUSE), Gainesville, FL. (Regional)

Burr, M., **Findley, K.**, & Whitacre, I. (October 2017). *Online simulations: What, how, and why?.* Presentation at Southern regional conference, National Council of Teachers of Mathematics (NCTM), Orlando, FL. (Regional)

Findley, K. (October 2017). *"Science-izing" the statistics standards*. Presentation at Southern regional conference, National Council of Teachers of Mathematics (NCTM), Orlando, FL. (Regional)

Findley, K. (May 2017). *Student-driven simulations for the statistics classroom*. Poster Presentation at 2017 United States Conference on Teaching Statistics (USCOTS), State College, PA. (National)

Findley, K., Burr, M., Whitacre, I., Schellinger, J., & Hensberry, K. (October 2016). *Discovering functions and geometric transformations with an interactive computer simulation.* Presentation at 2016 Annual Conference, Florida Council of Teachers of Mathematics (FCTM), Orlando, FL. (State)

Schellinger, J., Whitacre, I., Burr, M., Hensberry, K., & **Findley, K.** (October 2016). *Instructional approaches to support mathematical sense making using interactive simulations*. Presentation at 2016 Annual Conference, Florida Council of Teachers of Mathematics (FCTM), Orlando, FL. (State)

Findley, K. & Bose, R. (May 2016). *Investigating international statistics TAs' perceptions on pedagogy and professional development*. Presentation at Electronic Conference on Teaching Statistics (eCOTS) 2016 North Florida Regional Conference, Consortium for the Advancement of Undergraduate Statistics Education (CAUSE), Gainesville, FL. (Regional)

HONORS & AWARDS

2015-2018	**McDonald Scholar** – Florida State University, College of Education.
2013-2015	**Legacy Fellow** – Florida State University, University wide.
2015	**Nomination for Outstanding Teaching Assistant Award** – Florida State University, University wide.
2013	**Faithfulness and Loyalty Award** – Bryan College, College wide.
2013	**Outstanding Senior in Mathematics** – Bryan College, Mathematics Department.

MEMBERSHIP IN PROFESSIONAL ORGANIZATIONS

- Mathematical Association of America (MAA)
- Special Interest Group in the Mathematical Association of America (SIGMAA) on Statistics Education (STAT-ED)
- Special Interest Group in the Mathematical Association of America (SIGMAA) on Research in Undergraduate Mathematics Education (RUME)
- International Association for Statistics Education (IASE)
- American Statistical Association (ASA)

SERVICE TO THE UNIVERSITY

Florida State University

2018-2019 **Co-President -** School of Teacher Education Graduate Student Association (STEGSA)
2016-2018 **Treasurer -** School of Teacher Education Graduate Student Association (STEGSA)
2015-2018 **Assistant and Mentor -** Teaching in the Discipline Workshop, Statistics Department

Bryan College

2013 **Student Representative –** Curriculum Committee
2010-2012 **Vice President for Finance –** Student Government Association

SERVICE TO THE PROFESSION

Guest Reviewer for Refereed Journals

2017 Science Education
2017 Review of Science, Mathematics, and ICT Education

Service to Professional Organizations

2018 **Proposal Reviewer** – Annual Conference on Research in Undergraduate Mathematics Education
2018 **Paper Referee** – International Conference on the Teaching of Statistics
2017 **Proposal Reviewer** – North American Chapter of the International Group for the Psychology of Mathematics Education

SERVICE TO THE COMMUNITY

2016-2019 **MathPal** – United Way, Tallahassee, FL
2019 **Volunteer –** "Be My Neighbor" Day, Tallahassee, FL
2015-2018 **Teacher** – The Tallahassee Math Circle
2018 **Volunteer** – Mathematics Activity Days, Havana Public Library & Quincy Public Library
2018 **Co-Coordinator** – Kangaroo Math Competition, Tallahassee FL
2015, 2017 **Teacher of summer math/science courses** – Family Learning Center, Tallahassee Public Library
2016 **Teacher for extended school year** – Second Chance Summer School Program, Ghazvini Learning Center
2015 **Volunteer** – Math Fun Day, FSU Mathematics Department