An Investigation of Graduate Teaching Assistants' Statistical Knowledge for Teaching

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The purpose of this report is to provide a model of statistical knowledge for teaching grounded in an empirical study involving graduate teaching assistants (TAs). Research in statistics education has blossomed over the past two decades, yet there is relatively little research investigating what knowledge is necessary and sufficient to teach statistics well. In addition, despite the fact that TAs' role in undergraduate statistics education is integral, the research community knows very little about their knowledge of statistics and of teaching statistics. In this study, insights into TAs' knowledge of sampling concepts and their knowledge of student thinking about sampling concepts were gleaned from their engagement with sampling tasks during a task-based survey and three semi-structured interviews.

Introduction

Introductory college statistics is required for numerous majors, and enrollment in introductory college statistics courses has been steadily increasing for the past decade (Luzter, Rodi, Kirkman & Maxwell, 2005). Currently, many college students have no significant prior experiences with statistics in their K-12 education because only fairly recently have more substantial efforts been underway to include statistics in K-12 curriculum (National Council of Teachers of Mathematics [NCTM], 2000). As enrollment in introductory college statistics courses increases, teachers are faced with the challenge of teaching students with increasingly diverse educational backgrounds. Students who enter introductory college statistics classes with an insufficient knowledge base are likely to experience difficulty comprehending the different statistical tests and procedures required in such a course. In addition, many undergraduate statistics courses are taught by mathematics or statistics graduate teaching assistants (TAs) (Luzter, Rodi, Kirkman & Maxwell, 2005). While TAs teaching undergraduate statistics courses is not inherently problematic, it is not uncommon for TAs who majored in mathematics as undergraduates to enter graduate school having never taken a statistics course. Also, many TAs receive little preparation, orientation, or professional development before they begin their first teaching assignments (Speer, 2001). Undergraduate students with an insufficient knowledge base and graduate TAs with insufficient background and experience represent two immediate challenges in the teaching of introductory statistics at colleges and universities. These educational challenges have no doubt been part of the impetus of the statistics education community's recent recommendations for research investigating what knowledge is necessary and sufficient for teaching statistics well (e.g., Groth, 2007; Shaughnessy, 2007).

Borrowing the constructs of *common content knowledge* and *specialized content knowledge* developed by Ball et al. (2005), and Hill et al. (2005), and melding them with the Guidelines for Assessment and Instruction in Statistics Education (GAISE), Groth (2007) created a hypothetical framework of *statistical knowledge for teaching* (SKT). However, Groth's model is not based on any empirical research studies. Groth argued that empirical studies investigating SKT are necessary because the disciplines of mathematics and statistics are distinctly different, and there is a growing statistics education movement that has yet to address this topic. My paper heeds these recent calls by statistics educators in that it investigates TAs' statistical knowledge for teaching. The purpose of my research is to provide a model of SKT based on an empirical study of TAs. Specifically, my work focuses on TAs' SKT of sampling concepts, a concept crucial for understanding introductory statistics curriculum. For example, hypothesis testing and confidence intervals, the cornerstone of most introductory statistics curriculum, are based on theories of repeated sampling and the creation of sampling distributions. My paper makes a contribution to statistics education by providing a preliminary framework for the necessary and sufficient knowledge to teach statistics well.

Background Literature

I begin with some background literature to help orient the reader. Because this research integrates research in statistics education and research on TA knowledge, it is necessary to provide relevant background literature in both fields of study. Thus, I divide the background literature into two sections. First, I discuss research on teacher knowledge. Second, I address research on statistics education.

Research on teacher knowledge

With few notable exceptions (e.g., Kung & Speer, 2007; Speer, 2001), there is a paucity of research investigating TAs' knowledge. For this reason, researchers studying TAs tend to rely on research about teacher knowledge as a basis for informing their work with TAs. My model of SKT is grounded in research on *mathematical knowledge for teaching* (MKT) (see Ball, 2005; Ball, Hill & Bass, 2005; Hill, Rowan & Ball, 2005).

Through the construct of MKT, Ball and her colleagues (Ball, 2005; Ball, Hill & Bass, 2005; Hill, Rowan & Ball, 2005) highlight the special knowledge mathematics teachers need in order to successfully facilitate student learning. In particular, Ball and her colleagues deconstructed MKT into four primary components: (1) common content knowledge, (2) specialized content knowledge, (3) knowledge of *content and students*[1]; and, (4) knowledge of *content and teaching*. This deconstruction of MKT is an important contribution to research on teacher knowledge because it distinguishes certain elements of mathematical knowledge for teaching as distinct from pure content knowledge of mathematics. The first three components, common content

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[1] I add italics here to suggest that knowledge of content and students is one concept. That is, this construct represents the knowledge of how students make sense of and develop their understanding of specific mathematical content. Similarly knowledge of content and teaching represents knowledge of teaching particular content.

knowledge, specialized content knowledge, and knowledge of content and students, are particularly relevant to my study; thus, I discuss each in more detail below.

Ball (2005) defines common content knowledge as “the mathematical knowledge and skill expected of any well-educated adult”, including the ability to “recognize wrong answers, spot inaccurate definitions in textbooks, use notation correctly and the ability to do the work assigned to students” (p.13). Ball defines specialized content knowledge as “the mathematical knowledge and skill needed by teachers in their work and beyond that expected of any well-educated adult” including the ability to “analyze errors and evaluate alternative ideas, give mathematical explanations and use mathematical representations, and be explicit about mathematical language and practices” (p. 14). Ball’s construct, *knowledge of content and students*, fuses content knowledge with knowledge of student thinking and development in relation to the specific content. This fusion of knowledge of content and student requires: (1) knowledge of students’ mathematical development in a particular context; (2) the ability to comprehend students’ interpretations and incomplete thinking; and, (3) knowledge for how to best leverage students’ thinking to facilitate learning during instruction. The components of mathematical knowledge for teaching developed by Ball and her colleagues (Ball, 2005; Ball, Hill & Bass, 2005; Hill, Rowan & Ball, 2005) contribute to my framework of statistical knowledge for teaching by illuminating foundational components necessary for teaching any subject – *content knowledge* and *knowledge of content and students*. Also, their model provided a methodological consideration for my research study – a research design that enables the investigation of TAs’ knowledge of content, and of content and students.

Research in statistics education

In this section, I discuss two constructs from the statistics education community, *statistical literacy* and *statistical thinking*, which are particularly relevant to my framework of statistical knowledge for teaching. Assuming that only a relatively small percentage of the population will enter fields requiring advanced statistical knowledge, it is important to consider what statistical knowledge is necessary for the general population versus what statistical knowledge is necessary for the work of a statistician.

As societies become more information-based, technologically minded, and globally-oriented, their citizens will need to have a solid understanding of basic statistics in order to make well-informed decisions and be active participants in a modern democracy. But what level of statistical knowledge is required for informed citizenship? Probability and statistics educators have been addressing this question through the construct of statistical literacy. Just as literacy is often defined as basic reading and writing skills, statistical literacy includes the basic skills necessary for understanding statistical information. Yet, the term *basic* conjures up images of minimal skills, and statistical literacy is in many ways much more than this. According to Gal (2003), the construct of statistical literacy is geared toward *consumers* of statistics, where such consumption usually takes place through the media, internet sites, newspapers, and magazines. A person who is statistically literate is able to read, organize, interpret, critically evaluate, and appreciate statistical information presented to him/her by the media (Gal, 2002; Ben-Zvi & Garfield, 2004; Watson & Moritz, 2000). Statistical literacy, just as general literacy, is an expectation of adults living in industrialized societies because such knowledge supports informed public debate, improves people’s ability to make decisions regarding chance-based situations, and provides an awareness of social trends, such as crime, population growth, and the spread of diseases (Gal, 2003).

The work of a statistician (and other fields, such as actuaries) requires the ability to be a critical *consumer* and *producer* of statistics (Gal, 2003). The question, then, is what knowledge do statisticians need in their work? Pfannkuch and Wild (2004) investigated this question by researching the historical development of the field of statistics, and by observing statisticians work. Pfannkuch and Wild noticed that an important first component in the work of a statistician was the recognition that decisions cannot be made on anecdotal evidence; thus, sound sampling processes are essential in order to attain reliable data. Furthermore, the statistician must be able to understand the context she is working in, and then, subsequently, find meaning in, and build summaries of, the data, while acknowledging and accounting for the omnipresence of variability. That is, the work of a statistician requires sophisticated knowledge of the formal methods of statistical inquiry, including posing a research question, designing an experiment, gathering data, using formal statistical processes to analyze data, and drawing appropriate conclusions from the analysis. This level of knowledge is addressed in the statistics education community through the construct of *statistical thinking*.

One final point in need of mentioning is that sampling concepts are fundamental to the development of both statistical literacy and statistical thinking. Statistical inference is the process by which conclusions about a particular population are drawn from evidence provided by a *sample* from the population; thus, the quality of the sampling procedures affects the inferences statisticians draw from the data (Pfannkuch, 2005; Watson & Moritz, 2000). In order to understand, either informally or formally, the process of statistical inference, one must have an understanding of sampling concepts, including the act of sampling, building a sampling distribution, and obtaining measures of center and variability.

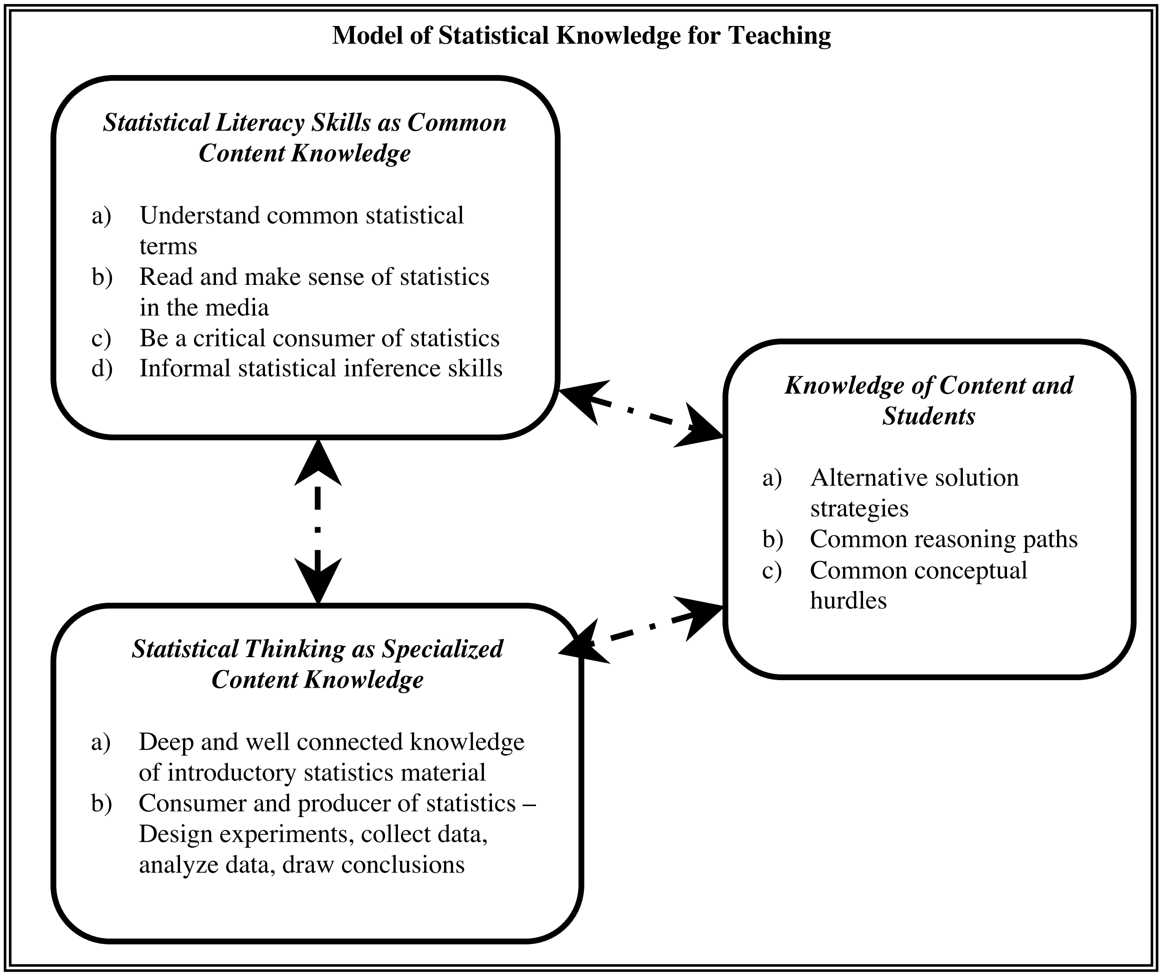
Fusion of research on MKT with statistics education

The primary question driving my research was, What do TAs need to know in order to teach statistics well? To begin to answer this question, I focused on connecting research on teachers with research on statistics education. The work of Ball, Hill and Bass (2005) primarily focused on the mathematical knowledge for teaching elementary school mathematics, yet I believe the constructs, *common content knowledge*, *specialized content knowledge* and *knowledge of content and students*, can be adapted to research investigating statistical knowledge for teaching. The construct of *statistical literacy*, discussed in the preceding section, serves as an illustration of *common content knowledge* when applied to statistics education. That is, the ability to be a critical consumer of statistics is knowledge we should expect of educated adults living in our society.

Ball et al. (2005) discussed specialized content knowledge as knowledge more specific to teachers in their work and beyond what could be expected from the general population. I argue that the construct of *statistical thinking* discussed in the preceding section serves as an illustration of *specialized content knowledge*. My general premise is that teaching undergraduate statistics well requires an understanding of the "big ideas" of statistics and the connections between and among statistical concepts. Without sufficiently deep knowledge of the *procedures* and *concepts* in a typical introductory statistics curriculum, (including basic probability, sampling, statistical inference, and the relationships between these concepts) TAs will be ill-equipped to articulate explanations in the classroom, and to facilitate an understanding of the process of statistical inquiry to their students. Thus, it is important that TAs be able to pose a well-specified research question, design an experiment, collect data, analyze data, and draw conclusions from the analysis, while keeping in mind the context, and while accounting for the presence of variability in the process. In addition, statistical thinking requires the ability to be a critical consumer of statistics, as well as a producer of statistics and thus it represents higher order thinking than statistical literacy. That is, if one possesses statistical thinking skills then he/she possesses statistical literacy skills, although improvements in statistical thinking can also act to strengthen one's statistical literacy (see Figure 1).

Knowledge of content and students includes the ability to recognize correct and incorrect alternative student solution strategies, common conceptual hurdles, and different types of student reasoning. This construct is easily transferable to my model of statistical knowledge for teaching. In addition, certain knowledge of content and students, such as the ability to recognize correct and incorrect alternative solution strategies, support and develop statistical literacy and thinking skills (see Figure 1). For instance, a statistician needs to see a problem from multiple vantage points, recognize erroneous data collection or analysis procedures, and communicate findings to clients who do not have a statistics background. Figure 1 provides an illustration of my model of statistical knowledge for teaching. The arrows suggest movement between the different constructs and that gains in knowledge in one area are likely to produce gains in knowledge in another area. It is important to note that this model emerged in part from my analysis of the data on TAs' reasoning about sampling concepts and their discussions of teaching sampling concepts to students.

Figure 1



Methodology

The two central aims of my research were to develop a rich and detailed understanding of TAs' (1) subject matter knowledge of sampling, and (2) knowledge of student learning in the context of sampling. Data collection methods consisted of a task-based web survey of 68 TAs from 18 universities across the United States, and a series of three 80-minute semi-structured interviews with a subset of five TAs taken from the larger survey population. The TAs in this study comprised a voluntary sample. Tasks used in the surveys and interviews were borrowed from, or modeled after, tasks used in other statistics education research studies (e.g., Shaughnessy et al. 2004a&b; Watson & Moritz, 2000; Lui & Thompson, 2005) for two primary reasons. First, borrowing tasks from prior research studies provided me the opportunity to test the viability of previously developed conceptual models characterizing the reasoning of K-12 students and teachers with that of graduate teaching assistants, and then, to subsequently modify such models as necessary for TAs. This process allowed me to develop conceptual models specifically focused on TAs' reasoning in sampling environments. Second, a primary goal of my study was to gain insight into TAs' knowledge of *content and students*. The Cognitively Guided Instruction studies (see Carpenter et al., 1988; Fennema et al., 1996) investigated teachers' knowledge of content and students through the use of prior research examining student solution strategies and student difficulties with addition and subtraction problems. The methodological implications of the Cognitively Guided Instruction (CGI) research are that a corpus of prior research studies on student solution strategies and difficulties can serve as a viable model for assessing teachers' knowledge of *content and students*. Thus, the tasks in my study were specifically chosen for the purpose of comparing and contrasting TAs' knowledge of student thinking and learning in sampling environments with that of the statistics education community's knowledge of student thinking and learning.

The Task

For the purposes of this paper, I discuss results from one research task. TAs who participated in the interviews were shown the Gallup Poll Task (see Figure 2) and asked to provide an initial interpretation to the task. After TAs had the opportunity to provide an initial interpretation and explanation for their thinking in the Gallup Poll Task, I provided them with several hypothetical student interpretations (see Figure 3). The hypothetical student interpretations were created based on common interpretations given by teachers in Liu & Thompson's (2005) study, as well as common student responses observed in my own introductory statistics students.

Figure 2

Gallup Poll Task

Your statistics class was discussing a Gallup poll of 500 Oregon voters' opinions regarding the creation of a state sales tax. The poll stated, "…the survey showed that 36% of Oregon voters think a state sales tax is necessary to overcome budget problems". The poll had a margin of error of ± 4%. Discuss the meaning of margin of error in this context (Liu & Thompson, 2005)

Figure 3

Hypothetical Student Interpretations of Margin of Error*

Student A says: The margin of error being 4% means that between 32% and 40% of all Oregon voters believe an income tax is necessary.
Student B says: We don't know if the interval 32% to 40% contains the true percentage of voters that believe an income tax is necessary, but if we sample 100 times, about 94 of those times the interval would capture the true percentage of voters.
Student E says: I can be 95% sure that all the sample statistics will fall within ± 4% of the unknown population parameter.

* Note: The different confidence levels expressed in Hypothetical Student B and E were used as a means to motivate TAs to question the confidence level for the Gallup Poll and then share the process by which the confidence level can be found. I do not discuss the results from TAs' investigations into finding the specific confidence level in this paper.

Confidence intervals are an important component of inferential statistics because a point estimate alone does not provide any indication of how close the estimate might be to the population parameter. A confidence interval, then, is an interval estimate together with an associated measure of reliability. From a frequency interpretation of probability, a robust concept image of confidence intervals requires an image of repeating the experiment over and over again, and thinking about the long-term relative frequency of the number of interval estimates that would capture the population parameter. In this interpretation, the confidence level refers to confidence in the sampling process; that is, one can be sure that a large percentage (typically 90% or 95%) of the intervals will capture the population parameter. A common alternative interpretation of a 95% confidence interval is that the *particular* interval calculated from the sample has a 95% chance of containing μ (the population parameter). From a mathematical perspective, this interpretation has a different meaning than the frequency perspective, in that the level of confidence is in the *specific interval*, rather than in the *method* by which confidence intervals are produced.

Hypothetical Student A's (see Figure 3) interpretation is quite common and one that can be found in many introductory statistics texts as a correct interpretation (e.g., McClave & Sincich, 2000). However, Student A's interpretation is problematic from an educational standpoint because it: (a) does not explicitly mention the level of confidence; (b) expresses confidence in the particular interval; and, (c) contains an implicit assumption that the population parameter moves; that is, that μ is *between* the interval endpoints, rather than *captured* by the interval. As a statistics educator, I argue it is preferable for students to develop a conception that supports the interpretation given by Hypothetical Student B (who explicitly mentioned the issue of confidence level and suggested an interpretation consistent with a long-term relative frequency perspective) because such a perspective supports a strong informal conceptual understanding of the basis of statistical inference. Hypothetical Student E's interpretation is more complicated in that it suggests an awareness of confidence level and an understanding of a distribution of sample statistics around an unknown population parameter; yet, it also suggests a possible source of confusion on the part of the student regarding the placement of confidence within the sentence. A robust alternative interpretation for confidence interval would be that 95%[2] of the sample statistics computed in the process of repeated sampling would fall within a certain distance of the population parameter. Unfortunately, Student E expresses confidence in the distance of the sample statistics from the population parameter *for all* sample statistics.

[2] Assuming a 95% confidence level.

The purpose of providing TAs with different student interpretations was to gather information on TAs' ability to make sense of student work and to ascertain whether or not TAs recognize common difficulties in student reasoning about confidence intervals. For instance, I wondered if TAs would: (1) recognize an alternative construal of confidence interval as looking at the distance of the sample statistics from the population parameter referenced in Student E's interpretation; (2) focus on the language and phrasing in Student E's interpretation; or, (3) question whether Student E's understanding was valid, and she simply had difficulty using the appropriate sentence structure to support her image.

Overall, the Gallup Poll Task raises important ideas that are foundational for understanding confidence intervals and margin of error. Some of the ideas I discussed above are "big picture" ideas (e.g., *statistical literacy*) necessary for making sense of polling information found in popular media sources. Other ideas, such as computing confidence level, require more sophisticated and detailed *statistical thinking* skills. Finally, the ability to make sense of student work, and to understand where students may struggle, illustrates knowledge of *content and students*. Table 1 provides a brief outline of necessary knowledge components for understanding the Gallup Poll Task and how those components fit within my model of SKT.

Table 1

Necessary Knowledge Components for Understanding the Gallup Poll Task & Hypothetical Student Responses	**Relation to Statistical Knowledge for Teaching Framework**
Understand the concept of confidence level in relation to the Gallup Poll	Statistical Literacy
Understand that the population parameter does not change	Statistical Literacy
Compute confidence level	Statistical Thinking
Understand the role of repeated sampling and the distribution of sample statistics in relation to the Gallup Poll Task	Statistical Literacy
Recognize alternative interpretations to the Gallup Poll Task	Statistical Thinking and Knowledge of Content and Students
Recognize common errors and developing concepts in student thinking	Knowledge of Content and Students

Analysis

There appears to be a continuum from which the TAs in my study reasoned about the Gallup Poll Task. Reasoning ranged from explicit and robust connections between confidence intervals and a distribution of sample statistics, to little or no connection to the distribution of sample statistics, but rather to confidence in the *particular* interval obtained in the sample. To illustrate these findings I share examples of TA responses to the Gallup Poll Task, along with my interpretation of their responses using the lens of the SKT framework I developed previously.

In TAs' initial responses to the Gallup Poll Task, three out of five TAs provided an initial interpretation equivalent to Hypothetical Student A – no mention of confidence level or repeated sampling. Two TAs raised the issue of confidence level in their initial discussions. The excerpt below contains Jack's's[3] interpretation of confidence interval.

> **Jack:** So we are saying with some degree of unstated confidence, nobody's saying what it is at this point, the true value is between 32 and 40.

Jack specifically mentioned confidence level in relation to the Gallup poll; however, his utterance, "with some degree of unstated confidence the true value is between 32 and 40", suggests an image that the *particular* interval obtained contains the population parameter and that the population parameter is not a constant value. One TA, Amanda, provided an initial interpretation that expressed the importance of confidence level and a subtle mention of the sampling process.

> **Amanda:** Well, in the most simplistic terms that means that 36% is our point estimate and our cushion provides room for 32 to 40%. It doesn't tell us much about what level of confidence they're using…. There's error involved in the sampling process, it's not an exact representation of your population. So with whatever level of

[3] All names used in this study are pseudonyms.

> confidence they chose we're looking at an estimate of the proportion being between .32 and .40.

Amanda's unprompted initial discussion of margin of error raises the notion of confidence and of "error involved in the sampling process". Although this information is not sufficient for inferring that Amanda holds an image of repeated sampling, she is the only TA who raised the issue of confidence in relation to the *sampling process* rather than in regards to the *specific interval* found from the sample statistic in her initial utterances.

It is not surprising that TAs did not explicitly discuss confidence level or an interpretation of the Gallup poll that entails an image of repeated sampling, as these ideas are often implicitly understood (or assumed to be understood) in the conversation. Thus, it is difficult to conclude from these initial interpretations that TAs did not have robust knowledge of confidence level or of the role of repeated sampling in interpreting confidence intervals. In fact, as TAs continued to interact with the task and were shown the different hypothetical student interpretations, all five TAs raised the issue of confidence level when interpreting confidence intervals. However, only two of the five TAs appeared to connect a long-term relative frequency perspective and the role of repeated sampling in the formation of a confidence interval.

On the one hand, as Amanda interacted with the hypothetical student interpretations, evidence mounted that suggested she had strong conceptions of repeated sampling in relation to confidence intervals. For example, the excerpt below shows part of Amanda's response to Hypothetical Student A's response.

> **Amanda:** That with a certain level of confidence the true proportion will be between 32 and 40%, but the truth of the matter is that the true proportion is either in this interval or it's not and this way of talking about it I think is very common…. but that we're actually talking about 95% of all samples would capture the true proportion and either our sample did or it did not.

In this excerpt Amanda indicated that Hypothetical Student A's interpretation is incomplete because it does not mention confidence level or the fact that the interval may not contain the true proportion. In addition, at the end of the exchange, Amanda provided an explicit image of repeated sampling, indicating that 95% of all samples would capture the population parameter. On the other hand, there was strong evidence that Jack appeared perplexed by any student interpretation that referenced repeated sampling. The following excerpt shows Jack's reaction to Hypothetical Student B's interpretation.

> **Jack:** Yeah that's not what this confidence interval says. It doesn't say a thing about re-sampling. It doesn't imply re-sampling. …I'm going to stick with my definition that it's not related to the re-sampling or the hypothetical re-sampling of it.

As Jack interacted with the other hypothetical student responses that entailed images of repeated sampling, he continued to question this image as a viable interpretation of confidence intervals. In fact, Jack became more explicit that the population parameter might not be inside the confidence interval, but rather that the confidence level is a measure of how likely it is that the interval contains the population parameter. Jack's reasoning suggested that his understanding of confidence level was in regards to the *particular* interval computed from the sample.

In addition to finding that TAs reasoned about confidence intervals on a spectrum ranging from no conceptions of repeated sampling to strong conceptions, I found that TAs did not demonstrate robust knowledge of content and students. In fact, all but one of the TAs I interviewed experienced difficulty interpreting alternative hypothetical student responses. As a result, these TAs often marked student responses that deviated from their own as incorrect. One TA, Amanda, was the only TA to discuss Hypothetical Student E's interpretation from the point of view of a sampling distribution. TAs' limited knowledge of content and students is perhaps less surprising, as TAs do not usually have opportunities to think about students' statistical development in their coursework and thus, it may not occur to them to think about student development in their teaching practices.

Conclusions

I found that the model of SKT I described at the beginning of this paper was a useful framework for thinking about the types and qualities of knowledge necessary to teach statistics well. For example, understanding the Gallup Poll Task at the statistical literacy level requires an appreciation of interval estimates and understanding of confidence in the sampling process. Understanding the Gallup Poll Task at the statistical thinking level requires additional understanding beyond the level of statistical literacy, including knowledge of the mechanics for computing confidence intervals and confidence level. Finally, understanding how students reason in the context of the Gallup Poll Task and common alternative conceptions they may have should serve to strengthen classroom instruction within this context. The findings from my study indicated that TAs demonstrated limited statistical knowledge for teaching in all three components of my framework - *statistical literacy*, *statistical thinking*, and *knowledge of content and students*. This finding differs from Kung and Speer (2007) in that the calculus TAs in their study demonstrated limited knowledge of content and students, yet had robust subject matter knowledge. Perhaps the difference in my findings of TAs' subject matter results have to do with the fact that most of the TAs in my study did not have extensive undergraduate course work in probability and statistics, whereas calculus TAs are highly likely to have taken the standard calculus sequence, as well as, an undergraduate analysis course.

The model of SKT developed from this research overlaps with the hypothetical framework offered by Groth (2007), despite the fact that the frameworks consist of a different fusion of constructs from the statistics education community. The overlap between the two models is promising because Groth envisioned empirical studies focusing on SKT as a means by which to extend and/or modify his hypothetical model. In addition, these findings have important implications for undergraduate statistics education. For example, these findings suggest that if TAs lack a deep and well-connected knowledge of introductory statistics material and/or knowledge of content and students, they are likely to experience difficulty teaching certain topics or making sense of student work. It is certainly plausible that limitations in TAs' SKT translate into deficiencies in student learning. In conclusion, my findings suggest that the statistics education community needs to further investigate the SKT of TAs and measure the subsequent impact of TAs' SKT on student achievement. Such research could serve as a basis for improving TA teaching through TA professional development and/or orientation programs.

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