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The Developmental Experiences of Exemplary Statistics Teachers

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The Developmental Experiences of Exemplary Statistics Teachers

Abstract

There has been a trend of increased statistical expectations for students and calls for increased statistical preparation for their teachers in recent years, but preparation has not yet reached recommended levels. A similar preparation gap existed at the inception of the Advanced Placement Statistics program, and this study examines a group of statistics teachers identified as exemplary by experts in the field to determine what challenges they faced and how they overcame them. Semi-structured interviews using a Communities of Practice framework (Wenger, 1998) were conducted. The challenges and responses to those challenges are identified, and these have implications for supporting new and established teachers of statistics at the K-12 level.

Keywords

Statistics education research, In-service statistics teachers, Advanced Placement Statistics, Professional development

The Developmental Experiences of Exemplary Statistics Teachers

Statistical literacy has become essential for the public: today, epidemiological models of disease and advances in artificial intelligence are routinely in the news. While improved statistical literacy is a goal for the undergraduate introductory statistics courses taken by hundreds of thousands of students each year (e.g., Raman et al., 2023), there has also been an increase in the expectations for statistical literacy of K-12 students over the past few decades. Beginning with the Principles and Standards for School Mathematics (National Council of Teachers of Mathematics [NCTM], 2000) and continued by the Common Core State Standards for Mathematics (CCSSM; National Governors Association Center for Best Practices [NGACBP] & Council of Chief State School Officers [CCSSO], 2010), there has been an increase in statistics outcomes for students, especially at the 6-12 level.

However, reports by professional organizations such as the *Mathematical Education of Teachers II* (Conference Board of the Mathematical Sciences, 2001, 2012) and the American Statistical Association's (ASA) *Statistical Education of Teachers* (Franklin et al., 2015) indicate that teacher preparation programs generally have not made changes to the ways that they approach statistics even as the curricula for students have changed. A typical teacher preparation program for secondary mathematics teachers includes an introductory statistics course (Banilower et al., 2018), but such a course is suitable only for developing common statistics knowledge and not the pedagogical statistics content knowledge required of teachers (Lovett & Lee, 2017, 2018). Reflecting this, recent surveys of preservice (Lovett & Lee, 2017) and in-service secondary mathematics teachers (Banilower et al., 2018) indicate widespread feelings of being unprepared or underprepared to teach statistics topics.

This is not the first time that an increase in statistical expectations has happened. Today, the Advanced Placement (AP) Statistics program is a thriving program with over 200,000 students taking the exam annually, and a teachers of AP statistics largely feel appropriately prepared (Lee & Harrison, 2021; Scheaffer & Jacobbe, 2014). However, prior to its introduction, a lack of teachers who were prepared to teach statistics was articulated as a key obstacle to the success of the AP Statistics program (Roberts et al., 1999; Scheaffer, 1997). For the AP Statistics program to be successful, the teachers involved in it were faced with – and overcame – many challenges. This study seeks to understand what challenges AP Statistics teachers faced and how they responded to them. Once these challenges and responses are identified, future work can determine to what extent they may benefit current mathematics teachers whose charge to teach more statistics is similar to that experienced by AP Statistics Teachers.

Background and Literature Review

Differences Between Mathematics and Statistics

Mathematics and statistics are different disciplines. Like physics and economics, statistics is a mathematical science–closely related to, but different from, the discipline of mathematics (Cobb & Moore, 1997; Franklin et al., 2007; Garfield & Ben-Zvi, 2008; Moore, 1988; Moore & Cobb, 2000; Rossman et al., 2006; Scheaffer, 2006; Usiskin, 2014). This distinction is not just a matter of semantics; rather, these disciplinary differences have implications for instruction that classroom teachers must address (Cobb & Moore, 1997; Franklin et al., 2007; Garfield & Ben-Zvi, 2008; Moore, 1988). There are many ways to distinguish statistics from mathematics, but the most germane for instructional practices at the school level are differences in thinking and reasoning and the real-world practices of professionals in the fields.

Despite similarities, statistical reasoning is different from mathematical reasoning and requires explicit instruction (delMas, 2004). Specific differences include the role of model abstraction and logical argumentation (delMas, 2004). Model abstraction is a type of reasoning found in both mathematical and statistical reasoning, but the different role that context plays in statistics is critical (delMas, 2004). Cobb and Moore (1997, p. 803) highlight the differing role of context saying, “In mathematics, context obscures structure … in data analysis, context provides meaning.” Of course, mathematics can benefit from context-driven instruction, but the importance of context and a connection to the real world through data is even more critical for statistics instruction (delMas, 2004). If teaching statistics is approached as teaching mathematics, the critical emphasis on real-world data and decisions relating to the context of the problem are likely to be omitted.

Research about Statistics Teachers

While much of the statistics education literature has focused on students, there is a growing body of literature focused on pre-service and in-service teachers. Research with pre-service teachers in the United States and internationally has shown that they are similar to other types of students in both their knowledge (e.g., Carlson & Winquist, 2011; Case et al., 2015; Groth & Bergner, 2006; Hannigan et al., 2013; Lancaster, 2008) and attitudes (Estrada, 2002; Estrada et al., 2004; Estrada et al., 2010; Hannigan et al., 2013; Martins et al., 2011, 2012). Fewer studies have focused on in-service teachers.

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The development of Colombian statistics teachers' identities in the context of professional development was studied by González and Zapata-Cardona (2014). Working with four teachers in a professional development setting modeled on Communities of Practice (Wenger, 1998), González and Zapata-Cardona found that the four teachers had different trajectories that resulted in viewing themselves as either a statistics teacher or not a statistics teacher. Ultimately, they conclude that experience teaching statistics may be more important to the construction of an identity as a statistics teacher than statistics training (González & Zapata-Cardona, 2014). This is similar to earlier work with Colombian in-service primary and secondary teachers' that found that their attitudes toward statistics improved with experience (Zapata Cardona & Rocha Salamanca, 2011).

In the United States, a survey of in-service teachers' motivations for attending the 2008 AP Statistics Reading was given to 183 high school teachers and 193 college instructors (Jacobbe et al., 2013). Survey results indicated that learning about students' misconceptions was the most beneficial outcome of attending the reading, followed by learning more about content, networking opportunities, and learning more about teaching, and ratings for these outcomes were higher for high school teachers than college instructors (Jacobbe et al., 2013). Other research with AP Statistics teachers has focused on their understanding of variability (Peters, 2009). Using an instrument developed for the study, five of the 12 participants were classified as having a robust understanding of variability and had similar personal characteristics to each other (Peters, 2009). Interviews about the development of the teachers' understanding revealed that major sources of development in understanding about variability were supportive environments, personal characteristics, and the teachers' roles (Peters, 2009, 2014).

Theoretical Framework

The research questions addressed by this study are: (1) What were experiences/problems/challenges encountered by mathematics teachers tasked with teaching statistics? and (2) What major experiences supported mathematics teachers in overcoming these problems? The theoretical framework used for this study is Communities of Practice (Wenger, 1998) was adopted to answer these questions. Communities of practice is a framework within situated learning, an educational perspective that accounts for knowing and learning in informal settings by accounting for the role of social interactions (Cox, 2005; Sadler, 2009; Wenger, 1998). A theoretical framework for understanding the experience of teachers of statistics should account for and emphasize informal learning as the formal statistical preparation of teachers continues to be insufficient for rising expectations (CBMS, 2001, 2012; Franklin et al., 2015). While Wenger's (1998) Communities of Practice framework is couched in terms of communities and social interactions, it is a useful framework for understanding the experiences of individuals (e.g., Cavanagh & Prescott, 2007; Goh, 2013; Hodkinson & Hodkinson, 2003; Kasworm, 2001). Communities of Practice does not presuppose particular groupings or social systems (Cox, 2005). Instead views professional practices as dependent on social processes, and so learning occurs through engagement with social processes (Cox, 2005).

Communities of Practice is a term to which many meanings are ascribed: several similar but distinct frameworks use the term (Cox, 2005; Kanes & Lerman, 2008), and within a framework the term can be used by researchers both describing or creating environments for learning (Hoadley, 2012). In this study, community of practice means a process for creating knowledge through the acculturation of new members into a group through legitimate peripheral participation (Hoadley, 2012; Macklin, 2007; Wenger, 1998). Members new to the community with little experience are able to participate in activities of the community and, over time, become acculturated into the practices and identity of the group (Barab & Duffy, 2000). In the context of a community of practice, increasing participation by the members of the community constitutes learning (Barab & Duffy, 2000; Hoadley, 2012; Wenger, 1998). Learning in Communities of Practice is also intimately connected to the development of an identity associated with the community of practice (Barab & Duffy, 2000; Wenger, 1998). This study will use Communities of Practice (Wenger, 1998) to identify and describe salient activities that led to the development of exemplary statistics teachers.

Methods

Participants

Participants were recruited using critical case sampling, a sampling strategy characterized by seeking participants for which the research can say "if it doesn't happen there, it won't happen anywhere" (Patton, 2002, p. 236). In this study, critical cases represent teachers who began as mathematics teachers and would ostensibly have a variety of experiences that affected their development into exemplary statistics teachers. Critical cases were identified by soliciting referrals from experts in the statistics education community with many connections on which to draw: the ASA-NCTM Joint Committee on Curriculum in Statistics and Probability (hereafter the Joint Committee) and an Assessment Specialist at ETS who was involved with the creation of the AP Statistics program. These experts were asked to identify "statistics teachers that you consider to be exemplary …

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primarily at the middle and high school levels" with no other restrictions (such as experience level or the type of courses taught). A list of 24 statistics teachers was compiled and contacted; all were known primarily for their work teaching statistics at the high school level.

To ensure the most diverse sample of participants possible, all teachers who wished to participate in this study were included. Data for this study were collected in 2015 from 12 exemplary statistics teachers in the United States who all taught AP Statistics. Among the 12 participants, there were five women and seven men. The highest level of education was a bachelor's degree for two participants, a master's degree for seven participants, and a doctoral degree for three participants. While many of the participants earned degrees in mathematics or mathematics education, there were several notable exceptions. One participant's highest education was a master's degree in statistics, and another participant earned a doctorate in statistics after he began teaching. Additionally, one participant earned a doctorate in a science. The participants were primarily mid-career and late-career teachers, having an average of 30 years of teaching experience; the minimum years of teaching experience was 7 years, the first quartile was 19.5 years, the median was 32.5 years, the third quartile was 42 years, and the maximum was 50 years.

Data Collection and Analysis

Data were collected using semi-structured telephone interviews; pseudonyms are used to refer to these participants. Because the research questions for this study focus broadly on the experiences that supported becoming an exemplary statistics teacher, questions on the interview protocol were informed by published interview protocols, including from studies that examined transition experiences and identity development from a variety of frameworks (e.g., Burton et al., 2013; Carlone et al., 2010; Krzywacki, 2009; Settlage et al., 2009). Additionally, due to the close link between learning and identity development in Communities of Practice (Wenger, 1998), writings about identity served to inform the interview protocol in a general sense (e.g., Gee, 1999, 2000; Juzwik, 2006; Philipp, 2007; Sfard & Prusak, 2005). An early version of the interview protocol was used in a small-scale study with one statistics teacher which allowed modifications to be made prior to this study's inception (Whitaker, 2015).

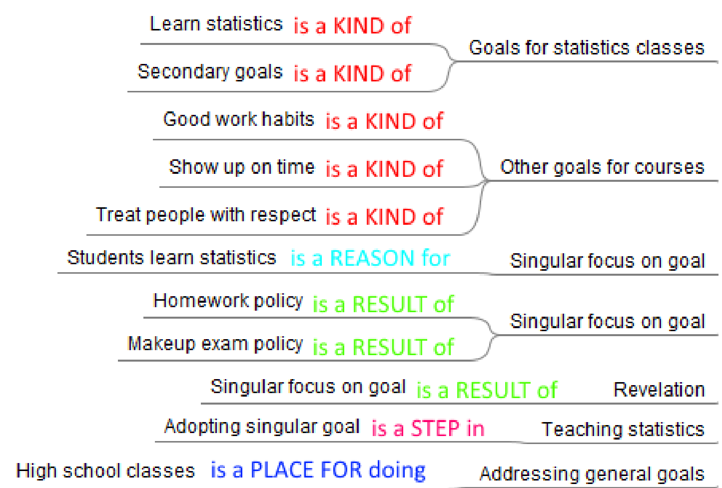
The data analysis was performed using an inductive analysis grounded in a constructivist epistemology as described by Hatch (2002). This process was characterized by repeated re-readings of the data and coding the data based on semantic relationships (Spradley, 1979, 1980) linked together by a cover term (Hatch, 2002). For an example of the codes, cover terms, and semantic relationships, consider the following excerpt with parentheses () and curly brackets {} added:

> when I think about (setting my policies for homework and makeup exams and things like that) {it's all with the single focus of I want my students to learn statistics rather than just some secondary goal and hopefully the statistics happens} [Paul:208-211]

This excerpt led to three codes linked to one cover term by two semantic relationships: the codes "Homework policy" and "Makeup exam policy" were linked to the cover term "Singular focus on goal" by the semantic relationship *cause-effect* ("X is a REASON for Y"), and the code "Students learn statistics" was linked to the cover term "Singular focus on goal" by the semantic relationship *rationale* ("X is a REASON for Y"). Each group of codes linked to a semantic relationship was referred to as a *domain*. A small excerpt of domains – including those from the example just described as well as from other parts of the data – is shown in Figure 1. Initially scores of domains were created because the data were analyzed at the level of phrases and sentences, though many of these were fragmentary or unimportant. The researcher then undertook an iterative process of rereading the data (and relistening to the data) and refining domains to identify domains that were salient for answering the research question. Based on these semantic relationship domains, themes were identified in later re-readings. Re-readings included confirming and refining codes and cover terms from previous readings and an active focus on codes that challenged and countered existing codes to identify areas where codes and cover terms did not fit the data well. The software FreeMind was used to organize the domains throughout the project (Mueller, Polansky, Foltin, & Polivaev, 2013).

Figure 1

Example of Domains



Data were also collected using three quantitative survey instruments: the Epistemic Beliefs Inventory (EBI; Schraw et al., 2002), the Indiana Mathematics Belief Scales (IMBS; Fennema & Scherman, 1976; Kloosterman & Stage, 1992), and the Survey of Attitudes Toward Statistics (SATS-36; Schau, 2003). Results from these instruments are presented elsewhere (Whitaker, 2020; Whitaker et al., 2022).

Results

In answering the research questions, two major themes emerged: disciplinary differences between mathematics and statistics and isolation within one's school that was ameliorated by fostering connections with a broader community. The participants in this study did not all have identical experiences, and Tables 1 and 2 summarize which participants' data supported each of the themes and sub-themes. For each of the themes summarized in these tables, data from at least 11 of the 12 participants supported at least one of the sub-themes.

Table 1
Summary of Participant Data Supporting Each Sub-Themes for Differences between Mathematics and Statistics Teaching

Pseudonym	Initial teaching experience	Teacher education	Activities	Textbook format and materials	No single right answer	Goals
Amber	X	X	X			X
Bob	X	X	X	X		X
Gregory	X	X	X	X		X
John	X	X	X		X	
Laura	X	X	X			X
Louie	X	X	X			
Patricia	X		X	X		X
Paul	X	X	X	X		
Ralph	X		X			X
Rebecca	X	X	X		X	X
Samuel	X	X	X		X	X
Tonya	X	X	X		X	X

Table 2
Summary of Participant Data Supporting Each Sub-Themes Isolation and Community

Pseudonym	Isolation	Workshops	Local PLCs	AP Statistics Reading	AP Statistics ListServ
Amber	X	X	X	X	X
Bob	X	X	X	X	
Gregory		X			
John	X			X	X
Laura	X	X		X	X
Louie	X	X		X	
Patricia	X	X		X	
Paul	X	X		X	X
Ralph	X	X		X	
Rebecca	X	X	X	X	X
Samuel	X	X		X	
Tonya	X	X		X	X

Differences Between Mathematics and Statistics Teaching

Differences between mathematics teaching and statistics teaching was a persistent, recurring theme with two primary components: preparation and the practice of teaching.

Preparation

In general, the teachers believed that they were not prepared to teach statistics the first time. Of the 12 participants, three had formal statistical training prior to becoming teachers. The remaining nine teachers all completed either an undergraduate mathematics major (eight teachers) or a mathematics education major (one teacher). While the backgrounds of the 12 participants in this study were different, none felt that their background was ideally suited to teaching statistics during the first few years of that experience.

Several of the participants reflected that teaching a statistics course for the first time was harder than teaching mathematics courses for the first time because they had never taken an introductory statistics course in the K-12 setting. Not having taken such a course meant that the statistics course was necessarily less familiar to teachers than other courses offered; Paul noted that “[statistics is] very different because pretty much any other math class you will teach you've already taken as a student in high school or college, so that makes it at least familiar in a lot of cases" [Paul:802-803]. The participants in this study were often familiar with the mathematics courses they taught because they themselves took the courses as students, regardless of when this was. With statistics, though, substantial changes – often driven by the increasing availability of computing in the classroom – have occurred in a relatively short time span and, even if one had taken a statistics course, such courses were not generally regarded as useful preparation by the participants. Participants reported being largely dissatisfied with the various statistics courses they took at the college-level and believed taking a course comparable to the ones they would teach is a helpful practice.

Participants with advanced statistical training were also not prepared to teach statistics. John had earned a master's degree in statistics, yet he did not feel that he was prepared to teach the AP Statistics course. This feeling of not being prepared did not stem from a lack of understanding of content, rather it instead reflects a misalignment between the topics covered in AP Statistics and advanced statistics courses. For example, while John had earned a master's degree in statistics prior to teaching statistics, his program did not emphasize all the topics covered in introductory statistics courses, specifically hypothesis testing and confidence intervals. Advanced statistical experiences were helpful to participants later in their careers but were not helpful in their initial teaching years.

Practice of teaching

Differences between mathematics and statistics were apparent for the teachers in the role of activities, how textbooks are structured, the (lack) of a single right answer, and their goals for their students. There is much support for the use of activities and other active-learning approaches in contemporary mathematics classrooms, and the teachers in this study were no exception: all recognized the value of using activities in their mathematics classes. Specific benefits of activities that were cited included that they allow students to see why a specific idea or topic is important and worth learning, they expose students to new contexts and ideas beyond the mathematics or statistics material, and they help teachers communicate their enthusiasm for the subject, which they believe may foster enthusiasm in the students. Teachers cited two primary barriers to using activities in mathematics classes: they are more difficult to do in mathematics classes than in statistics classes and being content with the traditional structure of a mathematics course. While participants recognized activities and other active learning strategies as useful for mathematics courses, the use of activities in statistics classes was viewed as easier to achieve and "absolutely essential" [Ralph:269] for student success, while the content and structure of mathematics courses led to the teachers incorporating fewer activities.

Another experienced difference between mathematics and statistics was related to the format of the textbooks. Paul, a teacher with substantial textbook-writing experience says that most non-college-level mathematics textbooks he has experienced are organized in a daily lesson format, with homework exercises clearly linked to specific topics and without long passages of prose. Statistics textbooks instead have long passages of prose and exercises that are not clearly linked to specific topics, in contrast with the textbooks used by participants in their mathematics classes which presented the information, examples, and problems in a format that is easily used in teaching daily lessons. Statistics textbooks shift more organizational work to the teachers, a non-trivial challenge for teachers new to teaching statistics.

Another difference between mathematics and statistics classes was how answers to problems are handled. Participants reported that, in mathematics courses, there tends to be a single correct answer while in statistics courses several answers may be considered correct for a given problem—even if the answers are contradictory. Note that this does not mean that all problems have more than one answer. Rather, sometimes there are multiple, legitimate ways to approach and explain a problem, and occasionally—though not often—these approaches may lead to different answers. As Tonya explains about statistics, "when you give a test question you might get two completely different answers. One might say 'yes' and explain why and someone might say 'no' and explain why and both of them are correct" [Tonya:553-560].

This plurality of acceptable answers for statistics problems made Tonya feel "very insecure" [Tonya:180] during her first few years of teaching statistics. Her perspective was that mathematics problems generally had a single right answer and a known method for finding it—this security is beneficial for someone teaching a course for the first time.

While there are similarities between mathematics and statistics at the school level, the teachers experienced mathematics teaching and statistics teaching differently. Participants generally described lessons, homework assignments, exams, and group work that were comparable between their mathematics and statistics courses and similar to their colleagues. Apart from these details, however, there were numerous instructional differences experienced by the participants. These experiences of differences between mathematics and statistics were a catalyst for the statistical development of participants. Another major experience which contributed to the development of participants was their experience of isolation as statistics teachers.

Isolation and Community

A critical challenge experienced by the mathematics teachers in this study while teaching statistics was being isolated within their respective schools. Most of the participants began their statistics teaching careers as the only statistics teacher within a school and continuing in this way was not unusual. Being the only statistics teacher within a school led to participants experiencing isolation. This experience of isolation was a challenging experience that the participants overcome by connecting with other communities outside their school and in ways that were dissimilar from how they interacted with communities as mathematics teachers. See Table 3 for a summary of which participants' data supports each of the sub-themes.

Reasons for isolation

The mathematics teachers experienced isolation from two sources: few teachers within a school were able or willing to teach statistics and demand for statistics – generally taught as an elective – generally did not warrant hiring a second teacher of statistics.

Isolation was experienced by most of the participants because they were "probably one of the only ones that really want[ed] to teach it" (Rebecca) or they "fell into" (Patricia) teaching statistics. In general, participants suggested that other mathematics teachers within their schools—who had similar backgrounds to the participants and thus would ostensibly be prepared to teach statistics—often disliked the subject and avoided teaching it. In other instances, participants were the only teacher in a school who had been to specialized training for statistics (e.g., training for new AP Statistics teachers). However, the initial reason for participants attending these training sessions that were available to other teachers is related to the wants and interests of their colleagues. Whether it was a lack of coursework, professional development, interest, or desire among other teachers, the result was the same: the participants were isolated among their colleagues "because nobody else [taught] the courses that [they did]" (Paul).

Not all of the participants began their statistics teaching careers in isolation, however. The few participants who could work closely with other statistics teachers within their school believed this close interaction was a great benefit. One participant, Ralph, "had the advantage—the huge advantage—of having a colleague who taught the course with [him]." For the few participants who had knowledgeable colleagues to work with, these close, local interactions allowed for frequent collaboration and support which was largely absent for the other participants.

Effect of isolation

The effects of isolation within their schools were keenly felt by participants. The direct consequence of the isolation that there were generally no colleagues within their schools that they could collaborate with or ask questions of. Amber describes this situation as challenging saying,

> One of the first challenges was not having anyone to be a soundboard for you.… Like where you have in algebra or pre-calculus there's going to be multiple teachers—you can work together. Having to work in isolation was really difficult in terms of teaching statistics. [Amber:231-234]

There are two components to this challenge: first, not having someone to work with and ask questions of when issues arise. Second, this situation did not occur with mathematics courses and so this change in situation was an additional challenge when participants were teaching statistics for the first time. Working in isolation meant that there was "[no] regular opportunity for collaboration" [Paul:407] within a school for statistics teachers.

While most of the participants in this study were the only statistics teacher in their school—at least at the beginning of their careers—a few did work in departments with other statistics teachers. The positive experiences of these teachers underscore the effect isolation can have on statistics teachers. Ralph was able to teach statistics for the first time with a colleague and describes working with such a colleague as a "huge advantage" [Ralph:242]. This experience of having the opportunity to work closely with colleagues while teaching a course was the expectation of participants when they were teaching mathematics courses and the exception when they were teaching statistics courses.

An important way that participants responded to the isolation they experienced within their schools was by forming supportive relationships with a broader community of statistics educators. Amber described her experience with developing contacts to support her statistics teaching by saying,

> I'd made friends… there was a couple of other people … [and] one person in particular that attended the first conference [I attended] so we sat side-by-side… we became good friends, and so I could email these people when I had questions and they would you know reply to me in terms of, "Yes, it's like this" or "No, it's really like this" or "this is how you do this probability problem" … I started making a network so that I could get help. [Amber:242-246]

Like Amber's experience, participants found support for their statistics teaching through a variety of statistics education community activities. There were many ways that participants formed these connections and different types of supports that ensued; these are described below.

Connections with community

The AP Statistics teachers in this study each made connections with other communities outside of their school that acted as surrogates for the types of interactions unavailable to them because of their isolation. Among the 12 participants, a wide variety of communities had been experienced, but not all were equally important to their growth as statistics teachers. For example, while many of the teachers had participated in conferences, these were not viewed as helpful to their development. The key types of communities that participants cited as being particularly influential on their development after the first few years of teaching statistics were the AP Statistics ListServ and the AP Statistics Reading. Workshops for new AP Statistics teachers were also commonly referenced as important, but in an indirect way: the lasting benefit of these workshops was that they served as an entry to the larger AP Statistics community. A few participants were members of local professional learning communities (PLCs). For these participants PLCs were a useful resource, but they were not as influential for development as a statistics teacher as the ListServ and Reading. The experience of teachers in these communities is described below.

The initial experience many participants had with the broader statistics education community was through workshops. The workshops that the participants experienced focused more on statistics content than did comparable mathematics professional development activities. Participants who had presented workshops described this emphasis as being in response to the desires and needs of the attendees, with Paul saying, “my experience working with teachers and workshops is they do really do crave the content” [Paul:747-748]. In their roles as both attendee and presenter, participants viewed workshops as a source for teachers to learn statistics content that they did not learn in their preparation.

Workshops are also a way to connect new statistics teachers with the broader community, and participants are encouraged to exchange email addresses and to attend other events such as the AP Statistics Reading. Bob says, “I think [the AP reading is] a great experience and after three years I encourage all of the participants at workshops to apply to be a reader” [Bob:487-488]. While helping new teachers connect with the broader community does not represent a large proportion of the time spent at workshops, it is an important aspect of the workshops.

Longer experiences such as residential workshops and the AP Statistics Reading were frequently cited as being important due to the types of informal interactions that were possible. The teachers in this study believed that the most important experience that they participated in was the AP Statistics Reading, a summer gathering lasting about one week to score the free-response portion of that year’s AP Statistics exam. At the AP Reading, teachers typically grade responses to a single question for the entire time they are there. Participants universally praised the reading as being instrumental to their growth as statistics teachers. Ralph said, "Most of what I learned about statistics I learned at those readings because it's just an incredible, incredible opportunity to learn stuff" [Ralph:58-60]. Likewise, Amber said "I attended the reading which I think is the best professional development there ever was" [Amber:38-39], and Bob said "There is not a school that could offer as good a professional development experience as going to the reading in my estimation" [Bob:475-476]. The key attributes of the reading that contributed to participants' growth were actual scoring of the exams, the residential nature of the reading, and the opportunity for growth and advancement as part of the formal structure of the reading.

One of the benefits of the AP Reading was being exposed to a large amount of student work. Participants reported that the many student responses that they were exposed to during the scoring often contained many different correct and incorrect types of responses. When asked about his experience with grading these responses, John described,

> You read hundreds and hundreds and hundreds of student papers … I think it helps me understand why students make [the] mistakes they make. When I see certain mistakes repeated over and over … or even sometimes just once with a strange kind of conceptual error the kid has, sometimes I'll make a mental note of it and [it] makes me think of things to take back to the classroom for my own students. [John:155-159]

Because John was able to see many different ways that students responded to the problem—many more than one teacher would encounter in a single year of teaching—he was able to develop a better sense of what mistakes students were apt to make and why; based on these mistakes that he learned about, he would strive to improve his own instruction. While scoring student responses is the raison d'être for the AP Statistics Reading, it was also an important component of why attending the reading supported participants' growth.

While the scoring of exams is the primary activity at the reading, even in this context one is "engaging in thoughtful, really deep conversations with other expert teachers" [John:154-155] over the meaning of student responses. There are also many opportunities for informal discussions with other attendees. Bob describes some of these interactions as, "I've had conversations with people about 'How do you actually teach [some topic]?' or 'Do you have an activity [for some topic]?' … you learn about how the grading happens in the discussions" [Bob:476-478]. These informal conversations were an opportunity for participants to have interactions similar to what they might experience within their own schools if they were isolated as statistics teachers. Without these residential experiences, John believes that he would have grown less as a statistics teacher nothing that, "Had I not had this really large group of knowledgeable skills and engaging people to interact with frequently, I would've never experienced the growth that I did" [John:233-234]. These informal conversations—and the lasting personal networks that were formed—were another aspect of the reading that supported teachers' growth.

A further benefit for the participants in this study of attending the AP Statistics Reading was due to its structure for increased responsibility. After one has been a Reader for several years, one is then eligible to be a Table Leader who helps other Readers. Very experienced Table Leaders are eligible to become Question Leaders who oversee the scoring for an entire question. This progression allowed participants to engage with the reading in a way that matched their ability levels and scaled gradually with their growth.

Another way to engage with the community was participation on the AP Statistics ListServ; this community is now called the AP Statistics Teacher Community but was still referred to by participants as the ListServ, and that language will be used here. Interactions in this community were asynchronous which allowed participants the freedom to choose when and how to participate. The ListServ was particularly helpful for the participants during the initial few years teaching statistics because it was a resource for getting informed answers to specific questions that they had. As Paul says, "Hearing the questions that other teachers have [and] hearing the answers that were provided to those teachers, having my own questions [and] getting them answered was super helpful" [Paul:314-316]. This quote from Paul illustrates that participation on the ListServ could take one of several roles: question asker, question answerer, and passive reader. Participants described newer statistics teachers as frequently asking questions and experienced statistics teachers as frequently answering questions, though they asked questions on the ListServ, too. This community, unlike the other communities that participants described, allowed for passive participation while still supporting teachers' growth. The ListServ was a resource that teachers could use to get answers to questions when they did not have colleagues who could answer them.

Some participants also had access to local professional learning communities (PLCs). In this usage, local should be taken to mean at the level of a school district or within a specified geographic area such as a large city rather than within an individual school. These PLCs were another surrogate for the interactions that could not take place within a school because of the isolation experienced by many statistics teachers. When PLCs were available to participants, they found that participation in them was a valuable experience because of the in-person interactions with teachers beyond their school that the PLCs afforded.

Conclusion

The research questions addressed by this study are: (1) What were experiences/problems/challenges encountered by mathematics teachers tasked with teaching statistics? and (2) What major experiences supported mathematics teachers in overcoming these problems? In answering the first question, two themes emerged: differences between mathematics and statistics teaching and the experience of isolation as a statistics teacher. The differences between mathematics and statistics teaching were challenges for the participants in the beginning of their careers, but as they developed as teachers the differences became ways that they could differentiate statistics classes from mathematics classes in meaningful ways such as by having different goals for their students.

With its emphasis on context and real-world applications of concepts, the literature suggests that statistics is a natural vehicle for teaching at least some aspects of quantitative literacy (Madison & Steen, 2003; Scheaffer, 2003; The Quantitative Literacy Design Team, 2001). Participants in this study saw statistics as a way of addressing the mathematical needs of a broader group of students than was served by traditional mathematics courses and was thus a means for achieving their mathematics goals. Similarly, while participants valued the use of activities and other hands-on approaches for learning in general, they perceived the use of activities in statistics courses as being easier and more natural than in mathematics courses.

Being isolated meant that teachers had few opportunities for legitimate peripheral participation (Wenger, 1998) within their own school. Instead, teachers engaged with various communities, namely the AP Statistics Reading, AP Statistics ListServ, conferences, workshops, and PLCs at a regional or district level—and serve a different role. Each of these offered an inbound trajectory (Wenger, 1998) for teachers to follow as they became statistics teachers. These community experiences were valuable for all participants in this study, but a few participants did have colleagues within their school who were knowledgeable about statistics. These teachers regarded this experience as both important for supporting their initial statistics teaching experiences and as unusual among the other statistics teachers they knew. These teachers still regarded participation in other statistics community activities as important to their development.

The AP Statistics Reading was overwhelmingly viewed as essential to participants' development, a finding which corroborates previous studies (Jacobbe et al., 2013; Peters, 2009). This is partly because of its residential nature which allows for the types of informal interactions unavailable to isolated teachers. Other aspects of the AP Statistics Reading that were particularly salient were action of scoring hundreds of student responses and the possibility of advancement within the hierarchy of the reading. Other communities were also valuable to participants but to a lesser extent than the AP Statistics Reading. Conferences and workshops were both helpful to nearly all participants, but their infrequent nature and generally short duration limited their effectiveness. Local PLCs were beneficial because they provided a space for somewhat routine local interactions and exchanges, but they were still infrequent, and few participants had access to such groups. Because the members of a PLC are not in close physical proximity often, a PLC does not provide opportunities for routine collaboration or impromptu conversations. Still, participants who were members of PLCs credited them with being important to their growth.

The AP Statistics ListServ was unique among communities described by participants because of its remote nature, allowing participants to read and post at times convenient for them. Additionally, reading the ListServ—without posting—was viewed as a legitimate form of participation. While the ListServ was able to serve as a surrogate for local interactions unavailable to isolated teachers, it was most useful for newer statistics teachers and participants generally participated less as they became more experienced.

A feature of these communities that was critical to the growth of teachers was their supportive, collegial atmosphere. Such an atmosphere was most prevalent in activities that had a residential component (e.g., longer workshops and the AP Statistics Reading) or had repeated interactions (e.g., the AP Statistics ListServ or local PLCs). In her study, Peters (2009) found that such environments supported teachers' understandings of variability because teachers saw the environments as safe and were free to ask questions.

Discussion

This study revealed that even exemplary statistics teachers can and do begin their careers unprepared for teaching statistics and without appropriate local resources to be successful. However, these teachers were able to identify ways to further their learning through various professional activities and communities. Due to increasing popularity of the AP Statistics course (Lee & Harrison, 2021; Scheaffer & Jacobbe, 2014) and the widespread adoption of the Common Core State Standards for Mathematics (NGACBP & CCSSO, 2010), more students and teachers in grades 6-12 are expected to know statistics. By and large, this increased statistical content is expected to be taught by mathematics teachers (Franklin et al., 2015) with little or no statistical preparation (Ben-Zvi & Garfield, 2004). Recommendations have been made for increasing the statistical preparation of teachers (e.g., CBMS, 2012; Franklin et al., 2015); these generally consist of recommendations for statistics courses that are designed for teachers and so emphasize pedagogical knowledge and deemphasize the mathematical aspects of statistics. This literature suggests that mathematics teachers can teach statistics well, but few would likely be prepared to do so without additional preparation. Few statistics teachers at the K-12 level are initially trained to be statistics teachers, leaving many statistics courses to be taught by mathematics teachers. That there are many excellent statistics teachers is a testament to the abilities of mathematics teachers. However, as with the participants in this study, the development into a statistics teacher that mathematics teachers undergo may be neither quick nor easy.

There are similarities between the experiences of the participants in this study and those of out-of-field teachers. Out-of-field teachers are those who are assigned to teach a course that is not aligned with their training, education, or certification (Ingersoll, 1998, 2001). The issue with out-of-field teaching is that teachers may lack the content and/or pedagogical knowledge needed to effectively teach their courses (Ingersoll, 2001). Studies of out-of-field mathematics and science teachers have shown that the supports that teachers receive as well as their personal resources are key to successful out-of-field experiences (Hobbs, 2012, 2013). Statistics is generally included in mathematics standards (e.g., NGACBP & CCSSO, 2010) and so the participants in this study would not typically be regarded as out-of-field, but they still acutely felt their lack of germane preparation. This suggests that the participants may have been practically out-of-field teachers when they began teaching, even if they were technically in-field teachers; it may be useful for schools to view new teachers of statistics as if they were teaching out-of-field for the purposes of allocating additional resources and supports for them.

While the development of statistics teachers was the focus of this study, the effect of isolation may not be specific to statistics teachers. In rural schools, there may be few mathematics teachers who also experience isolation because of the limited number of colleagues and comparing the experiences of rural mathematics teachers to statistics teachers may illuminate supports that benefit both groups.

This study is not without its limitations, and these are now described. The first limitation is related to the purposeful sampling method used: to identify critical cases (Patton, 2002), experts in the statistics education community were asked to nominate teachers that they believed were exemplary. However, by relying on nominations from experts there is a risk that some exemplary statistics teachers who were unknown to the experts were not considered, and this hypothetical group of exemplary statistics teachers may differ in meaningful ways from the exemplary statistics teachers in this study. For example, they may belong to different communities (that the nominating experts did not belong to) or they may not belong to any communities at all (and become exemplary in relative isolation). It stands to reason that there are exemplary statistics teachers in the elementary and middle school levels, and the nomination of exclusively secondary school teachers does suggest that some important groups were not accounted for.

Focusing on exemplary statistics teachers also limits the applicability of this study: this study is not generalizable to a larger population of statistics teachers. Instead, this study seeks to create transferable knowledge that may be useful in other contexts (Guba, 1981; Shenton, 2004). Which specific contexts the findings from this study may transfer to is unknowable to the researcher. However, because the participants in this study were not exemplary statistics teachers when they began teaching statistics, those working with other mathematics and statistics teachers, particularly as they begin teaching statistics, may find the results useful.

The results of this study suggest that there are challenges unique to teaching statistics that may be unanticipated by new teachers of statistics and that fostering community connections is a plausible way to overcome such challenges. In the context of AP Statistics, many of these communities are centrally organized and serve teachers well. However, the number of students exposed to statistics in grades 6-12 is at least an order of magnitude larger than AP Statistics enrollments (National Center for Education Statistics, 2015) and thus many more teachers need access to communities and do not have the benefit of a central organizing authority. Developing communities that effectively support the statistical development of teachers in grades 6-12 and help them overcome the challenges of isolation and distance—either through an easily replicable in-person system, an internet-based system, or both—is an open challenge that must be addressed if the potential arising from the inclusion of statistics in the CCSSM is to be realized.

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