Chapter 33
Teaching Teachers to Teach Statistical Investigations

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Abstract Despite its importance for the discipline, the statistical investigation cycle is given little attention in schools. Teachers face unique challenges in teaching statistical inquiry, with elements unfamiliar to many mathematics classrooms: Coping with uncertainty, encouraging debate and competing interpretations, and supporting student collaboration. This chapter highlights ways for teacher educators to support teachers' learning to teach statistical inquiry. Results of two longitudinal studies are used to formulate recommendations to develop teachers' proficiency in this area.

1 Introduction

Wild (1994) defined statistics as an inquiry process "concerned with finding out about the real world by collecting, and then making sense of, data" (p. 164). Despite calls for more emphasis on the investigative process (Moore, 1997), the focus in school statistics continues to be on calculations, procedures, and graphs (Sorto, 2006). Some countries now include statistical inquiry or investigations (implicitly or explicitly) in their national curriculum or curriculum standards (e.g., see National Council of Teachers of Mathematics [NCTM], 2000; Davies, 2007; New Zealand Ministry of Education, 2007; Australian Curriculum, Assessment and Reporting Authority, 2009), but it is uncertain the extent to which schools in these countries have successfully implemented statistical investigations.

Little research has focused on the whole inquiry process (Lavigne & Lajoie, 2007). Instead, much of the research in statistics education has centred on data analysis, predominantly with well-defined problems in which many of the difficult decisions have been obscured.

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This chapter overviews key understandings that teacher educators need to know in order to develop teachers' proficiency in teaching statistical inquiry. We focus in particular on the investigation cycle (see Pfannkuch & Ben-Zvi, this book, for further discussion of developing teachers' statistical thinking and MacGillivray & Pereira Mendoza, this book for further discussion of teaching statistics through projects and investigations). An example of a statistical investigation in a middle school classroom is used to illustrate each step of the investigative cycle. Challenges encountered in teaching investigations are discussed to alert teacher educators to key areas to focus their work with teachers. Two longitudinal studies are used to highlight ways that researchers have approached supporting teachers to develop this proficiency.

2 What Is a Statistical Investigation?

Wild and Pfannkuch's (1999) landmark paper described four dimensions of thinking used in statistical inquiry of authentic problems: Phases of the investigative process [Problem, Plan, Data, Analysis, and Conclusion (PPDAC)], types of thinking used, ongoing and iterative mental questioning (interrogating), and dispositions required. Problems in school statistics are frequently well-structured, where the planning, data collection, analysis, and conclusion are streamlined and unproblematic. Most problems in life, however, are ill-structured since the problem definition or solution pathways have a number of ambiguities that need to be addressed (King & Kitchener, 1994). They are sometimes unresolved with conflicting evidence, requiring students to consider potential causes of the problem, and generate multiple ideas on how to address it (Walker & Leary, 2008). Ill-structured problems often require discussion to negotiate which characteristics of a phenomenon can be measured to address the problem under investigation. For example, if the question being addressed is, "Which brand of bubble gum is the best?", then students will need to debate qualities valued in bubble gum that might qualify as "best" and identify possible measures to capture these qualities. Statistical inquiry situates statistical investigations within these complex settings. Below we give a brief example of a statistical investigation embedded in a middle school science unit designed to develop students' understanding of forces used in flight.

Problem. The driving question for this investigation was "What is the best design for a loopy aircraft?" At the beginning of the project, students constructed a loopy aircraft (made by affixing a paper loop to each end of a plastic straw). In performing initial test flights, they immersed themselves in the problem and negotiated how to define "best" to address the driving question. They defined "best" as the aircraft able to fly the greatest distance. Students also deepened their understanding of the science of flight through additional study.

Plan. In the second investigation step, students considered factors that could be altered on the loopy aircraft. They defined three variations (each) for the width, length, and placement of loops on the straw, requiring construction of 27 aircraft.

The students developed measurement protocols and a sampling design that would reduce unexplained variability and anomalies.

Data Collection. Once data collection was planned, students recorded flight distances of 5 flights for each of the 27 aircraft constructed. In reviewing the data, the students recognised a need to "clean" the data as measurements had been recorded with a mixture of meters and centimetres.

Data Analysis. When faced with 135 data points, students initially made superficial judgments about the best design (such as the single plane flying the greatest distance). In discussing this issue, they decided to add the five flight distances together to create a single measure for each aircraft to moderate the effect of anomalies. The teacher used this opportunity to introduce the mean. Students used *TinkerPlots* (Konold & Miller, 2005) to generate distributions of the mean distances to compare flights for each variable; for example, the distribution of distances of the nine planes with narrow wings could be compared to those with medium and wide wings.

Conclusions. Students used means to draw conclusions about the most advantageous width, length, and wing placement. Because the optimal width, length, and placement differed from the aircraft that flew the farthest, one student wondered whether they had ignored potential interactions between variables (a concept students might encounter in a second university statistics course). This raised the opportunity to initiate a new, more sophisticated PPDAC cycle with design modifications to further improve distance. At the end of the unit, students wrote a final report articulating their findings, conclusions, and justifications.

3 Assisting Teachers with Statistical Investigations

By breaking down the PPDAC cycle into its five phases, we draw on the literature to identify key issues to consider in teaching statistical investigations.

Problem. The problem-posing phase is essential in the investigation cycle as the investigation question acts as the initial "hook" and driving focus for the investigation. Research suggests that a critical aspect of this phase is for teachers to learn "to use the driving question to orchestrate a project" (Marx et al., 1994, p. 535). Questions developed for statistical investigations need to be:

- *Interesting, challenging, and relevant* (Groves & Doig, 2004). The flight unit was motivating to students as it tapped into their interest in paper planes and was of a low-stakes competitive nature. The level of cognitive engagement was challenging, but attainable for middle school students.
- *Statistical in nature* (Makar & Confrey, 2002; Arnold, 2008a). Questions need to be answered through gathering and interpreting data. In the flight unit, the students collected data to justify and defend their choice of "best" aircraft. The data also offered sufficient complexity to generate interesting results.

- *Ill-structured and ambiguous* (Borasi, 1992). Depth of investigation can be achieved by using questions which are ill-defined as they enable negotiation by students. For example, "What is the best design for a loopy aircraft?" raised issues such as whether "best" was an aircraft that flew the farthest, the most accurately, or spent the longest time airborne, each of which would lead the investigation into separate statistical areas.

There is significant scope here to assist teachers with the skills needed to develop problems worthy of investigation, or to guide students to do so (Allmond & Makar, 2010). One particularly critical aspect is the depth of knowledge and experience that teachers need to plan and conduct statistical investigations that develop rich statistical understandings (Arnold, 2008b).

Planning. School statistics often results in students being presented with data manufactured to demonstrate a pre-determined result. Teachers and students therefore have little experience with the reasoning and decision-making needed for planning data collection, recording methods, and appropriate statistical analyses. Research suggests that statistical content knowledge is viewed by teachers as the largest threat to perceptions of their competence (Hills, 2007) and thus suggests that with better statistical knowledge and experience, teachers could give students more support in planning investigations and making essential methodological decisions (Fielding-Wells, 2010).

Data Collection. Investigations enable students to choose their method of data collection, providing them with authentic feedback of their planning decisions that will generate deeper knowledge of methodology and efficiency (Krajcik et al., 1998). Therefore, it is important to help teachers recognise the deeper learning opportunities that arise when students are allowed to face problems and deliberate ways to resolve issues that arise during data collection.

Data Analysis. In most classrooms, data analysis is the entry point of student learning in statistics. Data presented to students have usually been cleaned and carefully selected to illustrate the lesson purpose, while in reality, data are more complex. Issues that arise in managing complex data can springboard discussions about treatment of outliers, errors, and unanticipated results. Allowing students to represent their own data also encourages the process of changing data representations to reveal alternate insights (Cobb, 1999). While time constraints are a valid concern for teachers, allowing students to identify errors and inefficiencies and negotiate alternate activities develops deeper understandings, perseverance, and efficiency.

Conclusion. The ability to communicate and critique statistical processes is necessary for the development of statistical literacy (Gal, 2002). In the conclusion phase, students interpret their results, reflect on the process, and draw critical inferences. At this time, teachers need to draw upon skilful questioning techniques and understanding of statistical analyses in order to facilitate students' reasoning in connecting their conclusions to the question under investigation and the evidence they have collected.

Other Issues. Through participation in the entire PPDAC cycle, students deepen understandings of the complexity of statistical processes. However, teachers need to allow students to make their own mistakes and support students in managing many of the challenges that arise. In doing so, they develop students' resilience and motivation as they implement plans and actions which result in improved understanding of their world. As a result, there is necessarily less order in the classroom that teachers often find counter-intuitive to teaching, with the noise and shifts in approaches to monitoring student behaviour confronting to existing classroom norms.

4 Challenges in Teaching Statistical Investigations

Developing students' inquiry skills requires teachers to engage students in statistical inquiry and support them through the investigative cycle. Those involved in teacher education and professional development must understand the nature of these challenges in order to support and validate teachers' experiences in learning to teach statistical inquiry. For example, teachers are typically frustrated with initial attempts at implementation (Anderson, 2002). "There is a danger that … initial difficulties with implementation and disappointment with student performance can lead to a premature rejection of [these] new pedagogies" (Krajcik et al., 1998, p. 341). Researchers have identified a number of issues to consider when supporting teachers to teach inquiry – in statistics, mathematics, and the sciences:

- *Envisioning inquiry*. Teachers often have difficulty envisioning inquiry in the classroom. Providing resources for teachers to use with students, allowing time to plan and learn collaboratively with other teachers, and creating opportunities to observe students in learning inquiry (R. Anderson, 2002; J. Anderson, 2005) will support them to develop this vision.
- *New teaching practices*. Teachers take on new roles when teaching inquiry, often requiring unfamiliar skills (Crawford, 2000; Arnold, 2008b). These roles highlight the diversity and complexity of teaching inquiry, reflecting shifts in the nature of teacher–student interactions. For example, the teacher takes on the role of motivator, modeller of inquiry practice, collaborator, and mentor. Teaching practices are extended with teachers becoming learners and innovators. Teacher educators can alert teachers to these new practices and discuss their implications.
- *Managing uncertainties*. Teachers need support to manage ambiguities and limitations in applying mathematical ideas. This will help them develop an ability in students to recognise the tentativeness of results, dependence on context, and that outcomes can be continually improved (Borasi, 1992). Experience as learners in conducting statistical investigations gives teachers direct experience in managing uncertainties (Makar, 2010).
- *Validation and support*. Emotional support and validation are needed for teachers to cope with new teaching practices, competing time and curricular pressures, and frustration (Marx et al., 1994). The discomfort and risk-taking needed by

teachers necessitates non-judgmental observations of their teaching, particularly in initial attempts (Hills, 2007).

- *Creating a classroom culture of inquiry*. Teachers need guidance to engender a culture of inquiry in their classroom. Extended time is needed to develop effective student collaborative relationships and to learn to engage students in meaningful discussions (Crawford, Krajcik, & Marx, 1998).
- *Content knowledge*. Disciplinary knowledge is central to teachers' ability to cope with the unexpected issues endemic to inquiry (Arnold, 2008b). Teacher educators should embed opportunities to develop teachers' content knowledge in investigations to model how teachers should develop students' content knowledge.
- *Accountability*. Support from teacher educators coupled with informal pressure or accountability is important for continuing improvement (Guskey, 2002).

5 Experiences in Assisting Teachers to Adopt Statistical Investigations

Teaching teachers to incorporate statistical investigations into their classrooms is an ongoing challenge. Workshops or short-term professional development programmes are not sufficient to sustain innovation. In these next two sections, we describe two projects aimed at developing teachers' practices over time which address many of the challenges we highlighted above. Both projects engage long-term scaffolds that assist teachers in adopting the curriculum and pedagogies associated with statistical investigations. Additionally, they focus on shifting teachers' epistemological beliefs about statistics from a set of methods and calculations, towards statistics as an investigative data-rich process of understanding the world. The first project, based on collaboration among researchers in the European Union, focuses on developing an online community of practice to support teachers in embracing statistical investigations (see also Meletiou-Mavrotheris & Serrado, this book). The second project, based on a longitudinal study in Australia, works with teachers both individually within their classrooms and collectively through regular professional development over several years to support their move to inquiry-based teaching in statistics. The diverse approaches of these projects are used to suggest ways to develop teachers' proficiency with teaching statistical investigations.

5.1 The EarlyStatistics (ES) Project

The aim of the project was to support teachers' knowledge of statistical investigations through online interactions and six modules that guided them through readings, teaching activities, and reflections. The online modules addressed key phases of a statistical investigation (problem-posing, data collection, data analysis, and interpretation), initial experiences in teaching statistical investigations, and

Table 33.1 Iterative stages in EarlyStatistics project

Stage	Aim
Initial moment. Preparation before classroom intervention	Analysis of: Statistical and probabilistic content; Official curriculum; Students' ideas; Models of intervention
Experimental moment. During classroom intervention	Activity: Plan their own scenario; Implement and report on classroom intervention
Reflection and Assessment moment. After classroom intervention	Reflect and assess: Statistical and probabilistic content developed; Students' learning outcomes; Classroom dynamics

reflections on their learning (EarlyStatistics Consortium, 2008; Meletiou-Mavrotheris, Paparistodemou, Mavrotheris, & Stav, 2008b).

The EarlyStatistics project design (Meletiou-Mavrotheris et al., 2008a) embraced characteristics of effective learning environments (National Research Council, 2000): Learning-centred, knowledge-centred, assessment-centred, and community-centred. It developed key ideas of statistical problem-solving using the GAISE framework (Franklin et al., 2005) through increasingly sophisticated levels of problem-posing, data collection, data analysis, and interpretation, with a focus throughout on variability concepts. Statistical tools such as *Fathom* (Finzer, 2005) and *TinkerPlots* were central to the work. To support teachers towards expertise with statistical investigations, project modules provided teachers with exemplars, classroom activities, and reflections (Table 33.1). These activities occurred through interactions with an online community of practice.

With an emphasis on reflection and teacher community embedded in experiences that build teachers' understanding and teaching repertoire of key ideas in statistics, the EarlyStatistics project highlighted the diverse ways that teachers adapt to teaching statistical investigations. For example, in their reflections, teachers focused on the significance of problem-solving in statistics, the difficulties of developing well-chosen statistical activities, the importance of creating a classroom environment that engaged students, or the challenges of envisioning and implementing statistical investigations (Azcárate, Serrado, Cardeñoso, Meletiou-Mavrotheris, & Paparistodemou, 2008).

5.2 Developing Expertise in Teaching Statistical Inquiry

The aim of this study was to understand development of primary teachers' confidence, commitment, and expertise as they gained experience with teaching inquiry in a supportive environment. Throughout the study, teachers designed or modified published units and taught three to four inquiry units per year to their students. Outcomes of the study produced a model (Makar, 2008) to describe the diversity of teachers' evolving experiences in teaching statistical inquiry over time, with four phases to describe common patterns in the teachers' classroom focus (Fig. 33.1) that are analysed below.

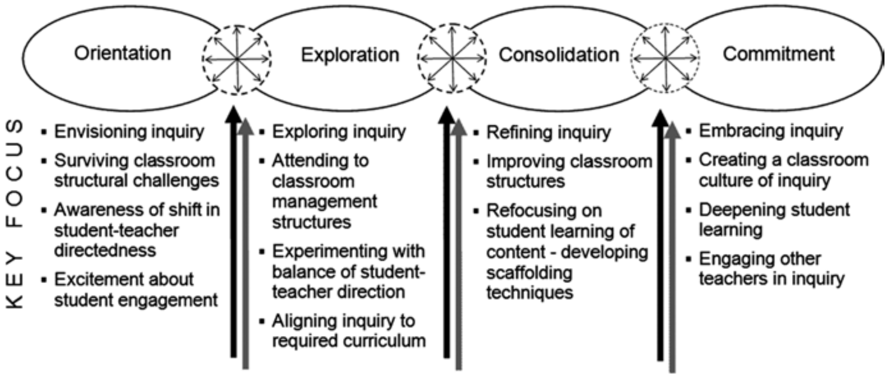

Fig. 33.1 A model of learning to teach statistical inquiry

Orientation cycle. The *orientation cycle* represented teachers' initial experience in teaching statistical inquiry. Being able to envision the inquiry process in a classroom setting was by far the most challenging hurdle for the teachers in this cycle (Makar, 2010). Teachers typically found their first unit quite difficult as they wrestled with unexpected learning outcomes that surfaced. They often blamed themselves for not anticipating outcomes rather than seeing this as the nature of inquiry. During their initial experiences, it was apparent that the teachers' main concerns were in envisioning what statistical inquiry is, coming up with an interesting problem, and engaging with structural aspects of their classroom (e.g., group work, eliciting and supporting student independence). Addressing these challenges became a focus of their teaching in the next cycle.

Exploration cycle. After the teachers experienced what a statistical inquiry looked like in their classrooms, they reacted to problems that had emerged. For example, they could see a range of potential directions in different phases of the PPDAC investigative cycle and responded to changing classroom management issues that arose in each of these cycles. The teachers continued to find logistical aspects challenging, like organising and coordinating group work, and helping students develop independence. Their growing experience helped them modify their teaching styles to begin to address these issues.

Consolidation cycle. By the next stage, the teachers had developed a "big picture" of what was involved in teaching a statistical investigation and worried less about management issues (e.g., classroom behaviours, logistical issues). They found it easier to design and locate rich driving questions to initiate the inquiry process, and in many cases, a new interest was emerging to deepen students' understandings of content by better structuring teaching of more subtle aspects of the inquiry process. Teachers in this phase felt more comfortable now negotiating the balance between student decision-making and providing scaffolding to help their inquiry stay focused. There was improved interest in supporting student learning, such as helping students make connections between the question being posed, the data they collected, and the conclusions being drawn (Hancock, Kaput, & Goldsmith, 1992; Fielding-Wells, 2010). The teachers needed to experience this issue firsthand in their own classrooms to better envision their roles in scaffolding students in this process. The *consolidation cycle* occurred after the teachers had taught with inquiry for a year or more and again emphasises the non-trivial nature of learning to teach statistical investigations.

Commitment cycle. After 2 years, some teachers were clearly committed to including statistical inquiry as a regular part of their teaching, as well as working to help other teachers develop and improve their teaching of inquiry.

6 Implications for Teaching Teachers to Teach Statistical Investigations

The process of learning to teach statistical investigations is complex. Research has been clear in the need to develop teachers' confidence with teaching statistical inquiry, but few opportunities exist for them to gain this critical experience. The two projects presented above were diverse in their approaches, but common elements suggest the following key characteristics are needed in teaching teachers to teach statistical investigations:

1. *Statistical content knowledge*. Although the EarlyStatistics (ES) project was more explicit in developing teachers' statistical content knowledge, both projects provided opportunities for teachers to deepen their understandings of the "big ideas" in statistics – variation, average, sampling, chance, and inference (Watson, 2006, see also Burrill & Biehler, in this book). The ES project developed these understandings through professional reading of statistics education literature while the Developing Expertise in Teaching Statistical Inquiry project developed statistical understandings by addressing concepts as they emerged within the statistical investigations teachers' learned and taught over time.
2. *Engaging in statistical investigations as learners*. Opportunities to experience statistical investigations as learners provide teachers with deeper understandings of complex statistical processes, such as the interrogating of data, modes of thinking, dispositions required, uncertainties and ambiguities encountered, and multiple interpretations and decisions made in each phase of a statistical investigation. These are often new experiences for teachers who are accustomed to mathematical structures and procedures that are more deterministic and predictable in their outcomes (see Gattuso & Ottaviani, in this book).
3. *Learning embedded in teachers' classrooms*. A key success of these projects was their ability to situate teachers' learning to teach statistical investigations within their own classrooms. The EarlyStatistics project supported teachers' classroom experiences remotely, yet engaged their classroom experiences as central to their learning to teach statistical investigations. They did not just *read* about statistical investigations but also *implemented* a statistical investigation and *reflected*

on their teaching. The Developing Expertise in Teaching Statistical Inquiry project partnered teachers and researchers within the teachers' classrooms over a number of years. Researchers played the role of a peer mentor in supporting teachers' development. These projects both connected teachers' learning to their own schools and maximised opportunities for teachers to transfer their learning to their classroom practices.

4. *Collaboration*. Teacher communities were key contributors to the success of both projects. By engaging teachers in collaboration with their peers and university researchers, the projects supported teacher professionalism and explicitly valued teachers' classroom expertise. The validation, collegiality, sharing of resources and experiences, and accountability as part of a learning community supported teachers in addressing challenges they encountered, particularly in their initial experiences teaching statistical investigations.
5. *Reflection*. Both projects provided teachers with time and opportunities for reflection on their learning to teach statistical investigations. Reflection is a powerful yet under-utilised tool for deepening learners' knowledge and understandings. In the case of statistical investigations, these reflections – both individual and communal – allowed teachers to recognise and attend to key contributors to their learning and improved the potential that they would apply these understandings to their students' learning.
6. *Long-term support and resources*. Finally, these projects both highlighted the importance of providing ongoing support and exemplary resources as teachers develop proficiency in teaching statistical investigations. This requires a shift from more traditional modes of teacher learning through workshops or coursework.

Although there were also significant differences in the way that these two projects were conducted, these common elements point to the need to be more conscious of the complexities in teachers' learning to teach statistical investigations. If we acknowledge and come to recognise the changing needs of teachers as they develop their expertise in teaching statistical investigations over time (Makar, 2008), new windows of opportunity for improving research and practice in this area will be provided.

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