OVERVIEW: CHALLENGES FOR TEACHING STATISTICS IN SCHOOL MATHEMATICS AND PREPARING MATHEMATICS TEACHERS[1]

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1. INTRODUCTION

For five years, a group of mathematics and statistics educators worked in collaboration to reflect on the teaching of statistics in school mathematics and on the training of those teachers who are responsible for this teaching, under the auspices of the International Commission on Mathematical Instruction (ICMI) and the International Association for Statistical Education (IASE). Results from this work are reflected first in the Proceedings of the Joint ICMI/IASE Study Conference held in Monterrey in 2008 (Batanero, Burrill, Reading, & Rossman, 2008) and second in this book. These two documents have contributed to raising awareness of the need for increased statistical content at school levels to improve statistical literacy in young students around the world as well as awareness of the related challenges in training and supporting mathematics teachers who teach statistics.

For each of the initial Topics in the Joint Study, this final chapter gives a reflective summary of the discussions held at the Study Conference (part of which were first analysed in Batanero & Díaz, 2010) and the main ideas discussed throughout this book.

2. THE SITUATION OF TEACHING STATISTICS AT THE SCHOOL LEVEL

As suggested by Batanero and Díaz (2010), reasons for including statistics at the school level were repeatedly highlighted over the last decades of the past century (e.g., by Holmes, 1980; Hawkins, Jolliffe & Glickman, 1991; Gal, 2002;), for example, the usefulness of statistics for daily life, the important role of statistics in developing critical

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reasoning; and the instrumental role of statistics in other disciplines and in many professions. More recently, the *Principles and Standards for School Mathematics* (National Council of Teachers of Mathematics, 2000) and the *Guidelines for Assessment and Instruction in Statistics Education* (GAISE) project (Franklin et al., 2005) were influential in further developing statistics education in the school curriculum in the United States of America and in other countries.

Papers included in the Joint Study Conference Topic 1 and in Chapter 1 in this book describe different perspectives and approaches to teaching statistics in the school curricula, depending on national policies, availability of resources within a country, and the relevance given to different topics and grade level. However, a general tendency is that statistics is now taught at very early ages in many countries; in some, six year-old children start studying basic statistical concepts and continue to develop these concepts in all the curricular levels until secondary school, where students may study elements of statistical inference. In addition, quick innovation and globalization in the past decade led to a new perceived complexity of reality that affected the mathematics curriculum, with a shift from content knowledge to competences (Gattuso & Ottaviani, this book) that has also been reflected in statistics.

3. TEACHERS' ATTITUDES, CONCEPTIONS AND BELIEFS

While the world is changing rapidly with respect to the prevalence and use of statistics, the curriculum in schools tends to be slow to respond to these changes. Although statistics as a content domain is widely accepted, typically statistics is not an independent topic in the school curriculum but is taught as part of mathematics. Consequently there is a need for a better preparation of primary and secondary school mathematics teachers, who are responsible for teaching statistics at these levels.

Teachers' statistical conceptions and beliefs deserve attention, since mathematics teachers' thinking is the key factor in any movement towards changing mathematics teaching and determines both the students' knowledge and the students' beliefs concerning mathematics and hence statistics (Batanero & Díaz, 2010). These issues were debated in the Joint Study Conference Topic 2 and in Section 3 of this book.

3.1. Teachers' attitudes and beliefs

Teacher education is usually focused on improving teachers' knowledge with relatively little attention paid to teachers' feelings, beliefs or attitudes. However, such

factors can influence the way teachers teach statistics and the extent to which teachers will apply statistics outside the classroom (Gal & Ginsburg, 1994). Research presented in the Joint Study Conference (Arnold, 2008; Estrada & Batanero, 2008; Lancaster, 2008) and summarised in this book (Chick & Pierce; Estrada, Batanero & Lancaster) suggests that, while teachers are willing to learn about and spend more time teaching statistics and acknowledge the practical importance of statistics, they feel their students experience greater difficulties in statistics than in other mathematical topics, and they consider themselves not well prepared to help their students face these difficulties.

Teachers also have beliefs about instructional goals and how they are linked with instructional content. For example, some teachers may have a dynamic versus a static view of mathematics and an orientation towards formal mathematics versus mathematical applications (Eichler, this book), which will in turn affect how they present topics in statistics. Thus, the implemented curricula for similar content might differ considerably depending on the teachers' objectives or beliefs.

Some researchers suggest that certain types of knowledge–including an understanding of how students learn specific statistical concepts–are best obtained in continuing professional development after the teacher has some experience in the classroom (Ponte, this book). However, there is lack of opportunity for teachers' professional development in statistics because they do not actually teach much statistics and rarely use statistics to analyse educational data even though in general it is relevant to their work as teachers.

3.2. Teachers' statistical knowledge

Many activities in which teachers engage, such as "figuring out what students know; choosing and managing representations of mathematical ideas; appraising, selecting and modifying textbooks; deciding among alternative courses of action" involve mathematical reasoning and thinking (Ball, Lubienski, & Mewborn, 2001, p. 453). Consequently, teachers' statistical knowledge plays a significant role in the quality of their teaching since teachers' instructional decisions in the statistics classroom are dependent on this knowledge (Batanero & Díaz, 2010).

This is cause for concern as the research summarised in this book shows that many teachers unconsciously share a variety of difficulties and misconceptions with their students with respect to fundamental statistical ideas. Examples of teachers' difficulties with statistical concepts described in this book include: having little real

understanding of the mean and median, having difficulties in creating or interpreting graphs; using only verbal reasoning with respect to variation, having little understanding of standard deviation as a measure of sample homogeneity; comparing distributions only in terms of averages; confusing correlation and causation; or viewing a statistical test as a mathematical proof of a hypothesis.

In addition to specific statistical concepts, teachers may have difficulty when implementing an experimental approach to teaching probability or teaching through statistical investigations (Stohl, 2005). Because few teachers have prior experience using statistical investigations to conduct probability experiments or simulations, they may miss opportunities to foster students' statistical reasoning when engaging students in statistical investigations or experiments. For example, their approaches to using an empirical approach to probability may rely almost exclusively on small sample sizes and fail to address the heart of the issue (Lee & Hollebrands, 2008).

3.3. Teachers' pedagogical content knowledge to teach statistics

In addition to being proficient in mathematics, Shulman (1987) described other types of knowledge needed by teachers to be competent in the mathematics classroom. Highly relevant to several chapters in this book is Shulman's conceptualization of pedagogical content knowledge (PCK) as a special mixture of content and pedagogy that is specific for a topic and that teachers develop as a consequence of professional practice.

Different models to describe the professional knowledge needed to teach statistics were discussed in the book. Some of them derive from frameworks taken from mathematics education and include complex components such as epistemology, instructional resources, knowledge about students' learning, capacity to implement adequate discourse and communication in the classroom, and capacity to adapt to the global school curriculum and social factors (Godino, this book).

Other authors (e.g., Burgess, this book) offer their own specific model of pedagogical content knowledge for statistics education that takes into account statistical reasoning (e.g., as described by Wild & Pfannkuch, 1999) or concerns the pedagogical expertise for effectively engaging students in learning data analysis and probability with technology (Lee, Hollebrands, & Wilson, 2010; Lee & Hollebrands, this book).

The scarce research related to PCK presented at the Joint Study Conference and summarised in this book suggests that the PCK required for teaching is often weak. For

example, in González and Pinto's (2008) research, pre-service secondary school mathematics teachers had no training in matters related to the curriculum and the processes of learning and teaching; had a scant knowledge of graphical representation; and did not perceive the different cognitive levels associated with graphs or the various components and processes linked to their interpretation. In another example, Chick and Pierce's (2008) research showed that some teachers lacked the competence to plan a lesson; they did not recognise the statistical concepts that could be developed from a particular task or data set and missed opportunities that are inherent in the task.

The last issue raised in Topic 2 was the need to prepare instruments to measure teacher's statistical knowledge (Callingham & Watson, this book). Questionnaires, with PCK items based on student survey items used in earlier studies and students' actual responses that ask teachers to predict a range of responses their students might give or how they might intervene to address inappropriate responses together with statistical analysis, can be used to obtain a measure of teacher expertise in relation to professional knowledge for teaching statistics.

4. ANALYSING CURRENT PRACTICES IN THE TRAINING OF TEACHERS, INCLUDING DEVELOPING COUNTRIES

Reports from different participants at the Joint Study Conference agreed that many of the current teacher training programmes do not yet adequately educate those who are teaching statistics for their task to prepare statistically literate citizens. Even when many prospective secondary teachers have a major in mathematics, few of them have received specific preparation in designing sample collections or experiments, analysing data from real applications or using statistical software (Batanero & Díaz, 2010). These teachers also need education in the pedagogical knowledge related to teaching statistics as described above, given that teaching mathematics is different from teaching statistics (see Franklin et al., 2005, or Burrill & Biehler, this book).

The situation is even more challenging for primary teachers, since in many countries statistics is included in the school curriculum for children beginning in grade 1 (6 year-olds). Clearly, teaching statistics to these children needs different approaches, tasks and methods than teaching statistics in secondary or high school, so primary school teachers, in addition to their knowledge of other basic disciplines, require a profound knowledge of children's cognitive development in statistics and probability. In spite of this need, few primary school teachers have had suitable training in either

theoretical or applied statistics, and traditional introductory statistics courses will not provide them with the didactical knowledge they need (Batanero, Godino & Roa, 2004; Stohl, 2005: Franklin & Mewborn, 2006). Papers included in the Joint Study Conference Topic 3 and in Chapter 2 discussed different examples of successful experiences with courses specifically directed to train teachers to teach statistics in different countries, some of them based on theoretical models prescribing how this training should be.

Topic 5, "Training teachers in developing countries", was included in the conference to engage countries to study their specific problems. Presentations from Bostwana, Central- America, China, Iran, the Philippines, South Africa and Uganda, among other countries, showed that the problems concerning the way in which teachers are specifically educated to teach statistics are similar to those described for developed countries. Because successful educational initiatives for teachers from statistical agencies or educational authorities in Central America, China, Iran, the Philippines, South Africa and Uganda were presented and discussed in other sections of this book, developing countries does not appear as a separate section.

5. EMPOWERING TEACHERS TO TEACH STATISTICS

Section 4 of the book collects together suggestions and experiences in the education of teachers that were presented at the Joint Study Conference Topic 4. A consensus in the chapters in this section is the need for finding meaningful approaches for preparing teachers, as teachers do not seem to automatically gain new knowledge through participation in professional development courses (Arnold, 2008). Some suggested approaches in the training of teachers include: promoting teachers' statistical literacy and statistical reasoning; engaging teachers with real data and training teachers with project work and statistical investigations; working with technology; and connecting teacher education to their own practice. Below are comments on these approaches.

Promoting teachers' statistical literacy (Ridgway, Nicholson, & McCusker, this book) *and statistical reasoning* (Pfannkunch & Ben-Zvi, this book). In many countries, statistical offices and agencies are providing resources that can be used to support the introduction of statistical literacy in schools. However, without wide-reaching education and professional development of teachers, such resources are unlikely to have an impact on students. Moreover, in order for teachers to develop a deep and meaningful

understanding of statistics that later they can use to help students develop the ability to think and reason statistically, it is important to create *a statistical reasoning learning environment* in courses they take that later they can use in their own teaching (Garfield & Ben-Zvi, 2009).

Engaging teachers with real data (Hall, this book) *and statistical investigations* (Makar & Fielding-Wells, this book). A conclusion of the Conference discussion was that teachers should experience the full cycle of research with statistical projects, if the goal is to change how statistics is experienced in the classroom Moreover, when time available for working with teachers is scarce, some papers (e.g., Godino et al., 2008; Batanero & Díaz, 2010) suggested that a formative cycle where teachers are first given a statistical project and then carry out a didactical analysis of the project can help to simultaneously increase the teachers' statistical and pedagogical knowledge.

Working with technology can be used both as amplifier and reorganiser to engage teachers in tasks that simultaneously develop their understanding of statistical ideas and allow them to experience how technology tools can be useful in fostering statistical thinking (Lee & Hollebrands, 2008). However, teachers also need adequate pedagogical knowledge about how to use technology in the statistics classroom.

Connecting teacher education to their own practice and promoting collaborative work among teachers (Ponte, this book) is essential to improving professional practice. It is through the exchange of ideas and materials among teachers who have common problems and needs that new ideas emerge for the introduction of new activities, new practices or new competencies (Arnold, 2008). In particular, a*nalysing collective case studies* and discussing teaching experiences and students' responses to given tasks can reveal the teachers' lack of specific knowledge of some statistical concepts and promote their statistical and pedagogical content knowledge (Groth & Shihong, this book). The affordances offered by modern Internet technologies provide new distance-learning opportunities for the pre-service and in-service training of teachers, making it possible to overcome the restrictions of shrinking resources and geographical locations and to offer high quality learning experiences to geographically dispersed teachers (Meletiou & Serrado, this book).

6. COLLABORATION IN TEACHER EDUCATION

Because of the inter-disciplinary nature of statistics, cooperation is both natural and beneficial for those involved in all aspects of statistics education. Topic 6 in the

Joint Study Conference solicited the presentations of successful experiences of collaboration between countries, institutions or university departments in the training of teachers. Book chapters that describe examples of such collaborations have been spread throughout different sections.

The preparation of mathematics teachers has historically been the responsibility of mathematicians and mathematics educators, although recently statisticians have started to play a major role in teacher preparation in a few countries (Batanero & Díaz, 2010). For example, in the United States of America the GAISE framework (Franklin et al., 2005) was written, in collaboration between mathematics educators and statisticians, to provide guidance to those involved with teacher preparation.

In addition, in many countries statistical offices and associations are increasingly involved in producing materials and organising initiatives to help increase statistical literacy. Two examples are North and Scheiber (this book) who describe the data and materials provided by Statistics South African and the Censusatschool project and associated professional development workshops provided by Canada's National Statistical Agency (Hall, this book). Other examples include work by the Philippines Statistical System and the Philippines Statistical Association (Reston & Bersales, this book), the Iranian Statistical Society (Persian & Rejali, this book) and the institutions collaborating in Guangzhou, China in teacher training (Shihong, Yongdong, Bangquan, & Reisheng, 2008). Collaboration between countries on research projects also served to join efforts of mathematics educators to develop a professional development programme for teachers (Meletiou-Mavrotheris et al., 2008).

7. NEW ISSUES RAISED AT THE CONFERENCE

The interest of mathematics and statistics educators towards this Joint ICMI/IASE Study is evident in the chapters of this book, many of which have been written by teams that have not previously collaborated and include people from different countries and different academic backgrounds. The Joint ICMI/IASE Study Conference Proceedings and now this book covered the topics and questions raised in the Study Conference Discussion Document, although not all of them with the same intensity. The discussions held during the Joint Study Conference showed the need to analyse the following new issues of particular relevance that would serve to orient future curricular development in statistics and that have been included in Section 2 of this book: fundamental statistical ideas; the role of probability in the statistics curriculum; the use of technology in

teaching and learning statistics; the differences and similarities of mathematical and statistical thinking; and the value of assessment in guiding the learning process. These issues are described below.

Fundamental ideas in the school statistics curriculum. Some common agreement about which basic ideas should be included at school level in number sense, measurement or geometry seems to exist with respect to international curricula, but there is no such agreement with respect to statistics, as curricula around the world show a notable variation. An important area of work was the identification of those statistical ideas that seem to be fundamental for understanding and being able to use statistics in the workplace, in personal lives and as citizens. Burrill and Biehler (this book) use different educational perspectives in statistics to propose a list of fundamental statistical ideas that should be taught to every student.

The role of probability in teaching and learning statistics. Although the focus of the study is statistics, since statistics and probability are linked in school mathematics in many countries and within mathematics theory and practice, a reference to probability in the book was needed, as didactic problems still need to be solved in the teaching of probability (Girard & Henry, 2005). Probability is a field that can connect to the study of mathematical modelling; but while probability theory often when taught in a finite context can be very simple, its abstract model part is not direct and could require a long period of learning (Chaput, Girard & Henry, 2008). Finally the school curriculum seems to ignore the subjective point of view of probability, which is widely used today in the applications of statistics (Carranza & Kuzniak, 2008).

Technology. Technology has changed many aspects of modern life, and this change has been reflected in statistics education. With software such as Fathom™ and Tinkerplots™ designed to support learning statistics, data analysis is no longer the exclusive domain of statisticians; students and teachers today can work on their own statistical projects and be engaged in the game of statistics, experimenting with the complete cycle of statistical reasoning (Wild & Pfannkuch, 1999). In addition to exploring data, technology now is used to explore complex statistical ideas or processes via simulation. Computer software offers the opportunity for students to learn about modelling, enabling students to build their own models to describe data and to generate simulations that can be explored. According to Pratt, Davies and Connor (this book), by taking advantage of this kind of software students can see real world phenomenon through a mathematical model (rather than seeing the model through the data).

Teaching through project work. Projects and investigations are ideal vehicles for student engagement, for learning to solve problems in context, and for synthesizing components of learning (Makar, 2010; McGilliwray & Pereira-Mendoza, this book). The emphasis should be on students posing their own questions about the data, interrogating the data, and learning new information about the real world from the data (Pfannkuch & Ben-Zvi, this book). The amount of data that can today be accessed on the Internet suggests that students can choose nearly any topic of interest to them for their work in the statistics classroom, which can increase student motivation. Working with real data also helps students investigate issues that do not often appear in textbook problems: for example, recognising different types of data, managing missing or incomplete data, defining variables and categories of classification, dealing with reliability and validity issues in measurement, designing questionnaires or experiments, screening data, and dealing with outliers (Hall, this book).

Mathematical and statistical thinking. An ongoing discussion in the statistics education community is how to make teachers aware of *statistical thinking* as something different from *mathematical thinking*, both of them being essential to modern society and complementing each other in ways that strengthen the overall mathematics curriculum for students (Gattuso, 2006; Scheaffer, 2006). The differences between statistics and mathematics are reflected in the philosophical, ethical, procedural and even political questions that are still being debated within statistics and its applications, a debate that does not happen often in most areas of mathematics. Statistics is much more closely related than mathematics to other sciences (from linguistics or geography to physics, engineering, agriculture or economy) where it is used as the language and method of scientific enquiry and from which many statistical methods were developed (e.g., agriculture). In this sense it is also easier in statistics than in mathematics to establish connections with other school curricular areas. In spite of these differences, teachers often teach statistics in a similar manner to the way they teach mathematics, which is not well-suited to the unique nature of statistics (Makar & Confrey, 2003).

Assessment. Assessment of student learning is an important part in every educational process as it provides information about student achievement in relation to the intended learning outcomes. Consequently, assessment has received much attention in statistics education in recent years (see, for example, Gal & Garfield, 1997). Garfield and Franklin (this book) analyse three basic components, *cognition*, *observation*, and *interpretation*, that underlie all assessment and that must be explicitly connected in

designing a coordinated whole relative to the purpose of assessment. In addition to the classical distinction between assessment *of* learning (summative), and assessment *for* learning (formative), the authors suggest that assessment *as* learning could combine both summative and formative methods and situate the student at the centre of the process, engaging students in new learning by monitoring and adapting their own understanding via the assessment process.

8. FINAL THOUGHTS

The success of the Joint ICMI/IASE Study indicateed that the time was ripe for collaboration between mathematicians and statisticians to address challenges related to the advancement of both teaching and research in statistics education and in the preparation of teachers to teach statistics. However, continuous changes and the rapid development of statistics education as part of the mathematics curriculum at the school level and the subsequent need for a better preparation of teachers imply that this collaboration is not finished with the publication of this book but should continue in the coming years.

While the chapters in the book provide directions to improve the education of teachers, it is important to expand the empirical base of studies to larger samples and different contexts to assure their validity. Thus, the hope is that the analyses, research and case studies presented and discussed in the book will provide a rich starting point for new research related to improving the teaching of statistics at the school level and the preparation of teachers to deliver that teaching. The recommendations for further research included at the end of each chapter constitute a rich research agenda and show the existence of statistics education as a research field where international collaboration is not only possible but fruitful.

Many people, across many countries, have contributed to the ICMI/IASE Joint Study and to the production of his book. Each has shown a keen interest in improving the teaching of statistics in school mathematics in one way or another but like all large-scale implementation of change there is always more that can be done. Now that you have read the book do not just put it down and forget. Focus on your area of interest, decide how you can contribute through teaching, research or teacher training, and become an active component of the changing profile of the teaching of statistics in school mathematics and/or the training of teachers to teach statistics.

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