PREPARING TEACHERS TO TEACH STATISTICS: DEVELOPING PROFESSIONAL KNOWLEDGE AND PRACTICE

Ana Henriques and Joao P. Ponte
Instituto de Educação, Universidade de Lisboa, Portugal
achenriques@ie.ul.pt

Teachers' professional knowledge is complex and trans-disciplinary, and is both informed by theory and practice. This paper addresses how teacher education systems may support the development of professional knowledge and teaching practices required for teaching statistics successfully. We discuss the content and nature of teacher knowledge about statistics as well as the teaching of statistics and their relation to teaching practices. We describe the aims, assumptions, and work carried out in an ongoing in-service teacher education program, that integrates teaching and learning with technology, for the professional development in statistics education of middle-school teachers. The teachers' professional development is supported by a continuous and reflexive movement that considers the articulation between theory and practice. Based on this work, we provide suggestions for teacher education practice and for further research.

INTRODUCTION

Data richness of today's society coupled with advances in technology (in particular, educational technology) led to important changes in statistics education. Accordingly, the current curricular orientations suggest a data-oriented teaching of statistics and the development of statistical literacy and reasoning (Franklin et al., 2007; NCTM, 2000) and point to a shift in teachers' attention from procedural (calculations and formulas) to more conceptual learning (statistical reasoning, interpretation and evaluation) (Ben-Zvi, 2000). However, a successful implementation of these changes in the teaching of statistics in schools depends on how mathematics teachers deal with topics that they never had taught before or had learnt to teach in their pre-service teacher education under a different paradigm of instruction (Batanero & Díaz, 2010; Smith, 2001). Since statistics has been introduced into mathematics curricula, often without adequate attention paid to teachers' professional development, they often depict insufficient understanding and a fragile knowledge for teaching statistics. Teacher education is therefore recognized as an essential element for supplementing the need of enhancing that knowledge in order to promote quality teaching and to meet the instructional goals (Batanero, Burrill & Reading, 2011).

Several researchers have argued towards new forms of professional development that consider the articulation between theory and practice and thus have a stronger possibility of influencing teaching practice (Ponte, 2011; Smith, 2001). In this paper we discuss the content and nature of teacher's knowledge for teaching statistics and how teacher education systems may support those forms of professional development. Finally, we describe the aims, assumptions, and work carried out in an ongoing in-service teacher education program, that integrates teaching and learning of statistics with technology, for the professional development in statistics education of middle-school teachers.

PROFESSIONAL KNOWLEDGE TO TEACH STATISTICS

Teacher's knowledge for teaching has been focus of extensive research, particularly since Shulman (1986) conceptualized "Pedagogical Content Knowledge" (PCK) as a special combination of content and pedagogy that is specific for a given content area and that teachers develop as a consequence of professional practice. Subsequent research on teacher knowledge discusses and expands Shulman's ideas in different models for professional knowledge to teach specific subjects. Ball, Hill and Bass (2005) develop the notion of "Mathematical Knowledge for teaching" (MKT) recognizing that is useful for teachers to have both subject matter knowledge and pedagogical content knowledge. Assuming that such knowledge is very different from the knowledge of mathematics needed by other professionals who use mathematics regularly, the authors suggested the concept of "Specialized Content Knowledge" (SCK) to describe the unique content knowledge required to support teaching activity and to make the mathematics understandable for students.

In K. Makar, B. de Sousa, & R. Gould (Eds.), *Sustainability in statistics education. Proceedings of the Ninth International Conference on Teaching Statistics (ICOTS9, July, 2014), Flagstaff, Arizona, USA.* Voorburg, The Netherlands: International Statistical Institute. iase-web.org

Even though those models are useful for the case of statistics as a topic that is included in the mathematics curriculum, several authors have argued in favour of its specificity, provided the established differences between statistical and mathematical reasoning (delMas, 2004; Franklin et al., 2007; Groth, 2007). Moreover, the actual recommendations for statistics teaching emphasizing exploratory data analysis (EDA) as well as the construction of students' conceptual understandings and the development of students' reasoning, call for teachers to have a deeper understanding of statistics and an ability to use new educational technologies, such *TinkerPlots*, effectively in classroom (Batanero et al., 2011; Franklin et al., 2007; Garfield & Ben-Zvi, 2008). Although teachers' instructional decisions in the classroom are dependent on their statistical knowledge (Batanero & Díaz, 2010), a wide statistical knowledge is not enough to assure the quality of teachers' professional competence and thus another type of knowledge and related skills are required, including knowledge about ways to effectively teach important statistical ideas, ways to help students use statistical software and technology tools, and ways to help prevent or overcome typical misunderstandings and misconceptions about statistical concepts. Teachers should also be able to organize the teaching, design learning tasks, use adequate resources, and understand the factors that condition the teaching and learning processes (Ponte, 2011). This justifies the effort to adapt and develop PCK or MKT models to describe the professional knowledge needed to teach statistics. For example, Burgess (2006) developed a specific model of PCK by crossing the components in teachers' knowledge described by Ball et al. (2005) with the essential types of statistical reasoning defined by Wild and Pfannkuch (1999). Groth (2013) provided a more general framework for "Statistical Knowledge for Teaching" (SKT), adapting his previous work (Groth, 2007) to include more recent ideas of Hill et al. (2008). The increasing use of technology in the classroom calls for attention to what specialized knowledge teachers need for effectively engaging students in learning statistics with technology. The work of Lee and Hollebrands (2008) described "Technological Pedagogical Content Knowledge" (TPCK) which may be regarded as an attempt to combine three main knowledge domains - content, pedagogy and technology - and include some of the essential competencies required for technology integration in teaching statistics: (a) statistical knowledge, (b) understanding of how to use technology to explore statistical ideas, and (c) understanding of pedagogical issues related to teaching statistics (Mishra & Koehler, 2006).

Teacher's knowledge, however, cannot be disentangled from the complexity of the systems in which it takes place (Ponte & Chapman, 2006). These authors argue that in their practices, teachers act on the basis of what they know, without separating the intellectual or formal knowledge from the practical, required to identify and solve professional problems. In this perspective, teachers' beliefs and conceptions are also relevant elements of teacher's knowledge. Therefore, professional knowledge, sometimes named as "craft knowledge" (Ruthven & Goodchild, 2008), is deeply personal and oriented to teaching practice, although grounded on theoretical knowledge and experiential elements (Ponte, 2011; Smith, 2001). Concerning the particular case of statistics, Ponte (2011) argues that professional knowledge required for teaching statistics combines: (a) knowledge of students, including their learning processes, thinking strategies, most common difficulties and cultural and social aspects that influence their scholar performance; (b) knowledge of the curriculum, including purposes, levels of development, how statistical ideas are articulated; and (c) knowledge of teaching practice, including the planning for instruction, conducting the classroom activity, and reflecting on teaching practice. This view of "craft knowledge", produced in professional practice, has important implications for teacher education since it reinforces the perspective that in-service teachers have needs and capabilities that it is necessary to discover, value and develop through a natural "professional development" path, leading them to learning and changing practices (Ponte, 2011).

PRACTICE-BASED TEACHER EDUCATION: DEVELOPMENT OF PROFESSIONAL KNOWLEDGE TO TEACH STATISTICS

The complexity and demand of a teaching aligned with the referred recommendations for addressing some fundamental ideas (such center, variation, distribution, sampling and inference, among others), which differs significantly from the usual practices, require personal and professional changes in teachers (Shulman, 1986; Sowder, 2007). Teachers need a positive personal relation with statistical ideas as well as to develop the capacity to plan, conduct and reflect

on such innovative practices that meet what is envisaged in the current curriculum guidelines for statistics (for example, adopting new curriculum orientations, selecting new kinds of tasks, creating new classroom environments, and promoting dialogic communication). Teacher education for in-service teachers is therefore challenged to promote their professional development process, focusing on these attitudes and competencies.

Recent perspectives on teacher education emphasize the importance of designing professional development programs that build on and benefit from teachers' current instructional practices and, at the same time, are effective in pursuing a professional development agenda (Ponte, 2011; Smith, 2001). Moreover, 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 and new ways of work (Arnold, 2008). In this way, rather than have teachers learning theories and applying them to practice, professional development programs needs to involve teachers in collective activities to share knowledge base for teaching that emerge from closely examining practice.

A distinguishing characteristic of a good teaching practice is reflected in the richness of the ways in which the teachers see and interpret their practice not just in the actions that they take. Accordingly, the reflection, framed as reflection in practice (Schön, 1983), plays a central role in teacher's professional development since, when they reflect, teachers become more confident in their ability to handle statistics in a different way, identifying its weaknesses, but also its potential (Llinares & Kainer, 2006).

PRACTICE-BASED PROFESSIONAL DEVELOPMENT PROGRAM IN STATISTICS

There are many ways to put in practice the ideas outlined in the previous sections aiming to support in-service teachers to teach statistics under a new paradigm. In this section we briefly describe the aims, content and structure of an on-going practice-based professional development program in statistics for middle-school mathematics teachers[1].

This program strives to develop teachers' understanding of how sequences of instructional activities based on the use of technology promote students' statistical reasoning. It is therefore designed taking into account the basic principles of Cobb and McClain (2004) and the integration of technology (specifically the dynamic statistics software *Tinkerplots*) with current curricular ideas. Central to the program design is also the assumption that learning is a social activity best supported through collaborative activities and particular care has been taken to build on participating teachers' knowledge and experiences. Teachers develop knowledge of statistics teaching by engaging in joint activities and discussions, helping each other, and sharing ideas about possible pedagogical strategies, use what they learn to their classrooms setting, and after that they reflect about their students' learning and the tasks and technology's role in that process. In that way, the program was designed to help teachers to become knowledgeable and reflective in the subject of statistics by developing three components of professional knowledge: knowledge of the curriculum, knowledge of students and knowledge of teaching practice (Ponte, 2011). The goals for the teachers who attend the program are to: (a) become aware of the importance of statistical reasoning as a goal of statistics education; (b) become knowledgeable about current guidelines for teaching statistics (GAISE recommendations) and use them in their practices to develop the "big ideas" that form the foundation for statistical reasoning (e.g., data, variability, distribution and inference); (c) gain experience in planning and conducting classroom activities aiming to develop students' statistical reasoning using the statistical software *TinkerPlots*; (d) make sense of individual students' statistical interpretations, reasoning processes and difficulties; and (e) select and adapt instructional tasks to implement in classroom aiming to develop students' statistical reasoning.

The program extends for a period of six months, with a face-to-face working time of 40 hours (the teachers work another 40 hours autonomously in pairs or individually) and is attended by 11 teachers. It is organized in 12 working-sessions of about 3-4 hours each and follows a teaching experiment design (Cobb, Confrey, diSessa, Lehrer & Schauble, 2003). In the first three sessions, teachers are introduced to the objectives and pedagogical framework underlying the course, through assigned readings and discussion of actual curriculum guidelines and previous research related to statistics education (e.g. Fitzallen & Watson, 2010; Franklin et al., 2007;

Garfield & Ben-Zvi, 2008) and get familiarized with the facilities offered by the *TinkerPlots* supported on a task which is oriented by a prepared tutorial and using the *TinkerPlots* database. In this very short period of time, the teachers became independent users of the software as they tended to use *TinkerPlots* creatively, instead of following the procedures in the tutorial. Teachers also recognized the potentialities of such software for teaching statistics although they are expectants in relation to its use in the classroom.

The focus then shifts to a first cycle of three phases: lesson planning, teaching and teaching analysis. In the lesson planning phase, teachers and teacher educators jointly select and adapt or produce tasks and materials and plan a sequence of lessons aligned with the SRLE principles (Garfield & Ben-Zvi, 2008). The teachers' practice is at the center of the program since, in the sessions, the teachers work on the tasks that they will use in the classroom. Teachers' first choices were on tasks carefully designed using meaningful contexts in which students are challenged to formulate questions based on real data (both collected by students and given to them), before analyzing them employing the software *TinkerPlots* and to make data based inferences. They also discussed ways of promoting classroom discussions and students' collaborative work.

In the following phase, one or two teachers for each educational level implement in their classroom the sequence of tasks designed and planned in the sessions. The teachers are often supported by other teacher participant, of the same educational level, who helps in data collection. Once the teaching phase is completed, teachers report on their experiences, including a critical analysis of their work and that resulting from their students and select episodes of their teaching which become the objects of jointly reflection and discussion in the next program sessions (teaching analysis phase). They share essential information to gain additional insights on how to further improve the proposed tasks and their teaching practice. Based on previous experience and evidence (data collected from the videotaped discourses during the teaching and teaching analysis phases), the teachers and the teacher educators together review and discuss the lessons used in previous cycle to improve the tasks and the conditions for their implementation in the classroom and begin another cycle of teaching and teaching analysis. It is planned to carry out three cycles, providing a set of tasks and a description of the teaching practice related to the different contexts and educational levels to which the planning is orientated (Figure 1). The program also involves a research component as teachers have the opportunity to research their professional practice, with the design of instruments for data collection and the analysis and reporting of results.

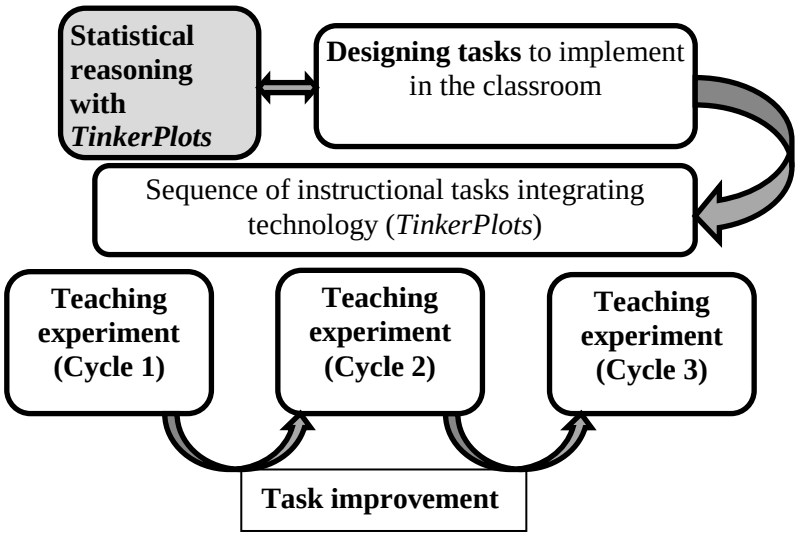

Figure 1. Structure of a practice-based professional development program

CONCLUSIONS/IMPLICATIONS

This paper briefly discussed the need to develop teacher's knowledge for teaching statistics through a professional development process that considers the articulation between theory and

practice, not favouring one over the other. At this point, the first cycle of teaching and teaching analysis of the practice-based professional development program presented in this paper is finished and it is apparent that it offers an effective way to teachers have a better appreciation of what teaching statistics is, under the current statistical education recommendations. Supported by collaborative and reflexive activities, teachers questioned their own established way of teaching statistics, felt encouraged to consider and to try different pedagogical approaches in their own classroom, more closely aligned to current curricular orientations and integrating educational technology, being able to assess the impact of such teaching on the learning of their students and, at the same time, developed their understanding of statistical concepts and ideas. However, we continue to evaluate and revise our program so that can be improved and further research on the activities and results of such program is needed for ascertaining whether it has a real impact on teaching practice and therefore on developing students' statistical reasoning.

(1) Note: This program has been implemented under the project "*Developing statistical literacy: student learning and teacher education"* (Oliveira, Henriques & Ponte, 2012) and was designed by its coordinator (Hélia Oliveira) and the first author, both teacher educators in the program.

ACKNOWLEDGMENTS

Study supported by national funds through FCT – Fundação para a Ciência e Tecnologia, Project "*Developing statistical literacy: student learning and teacher education"* (PTDC/CPE-CED/117933/2010). Thanks to Hélia Oliveira for her helpful comments on this paper.

REFERENCES

Arnold, P. (2008). Developing new statistical content knowledge with secondary school mathematics teachers. In C. Batanero, G. Burrill, C. Reading & A. Rossman (Eds.), *Joint ICMI/IASE Study: Teaching Statistics in School Mathematics. Challenges for Teaching and Teacher Education. Proceedings of the ICMI Study 18 and 2008 IASE Round Table Conference*. Monterrey, Mexico: ICMI and IASE.

Ball, D. L., Thames, M. H., & Phelps, G. (2005). *Articulating domains of mathematical knowledge for teaching*. Online: www.personal.umich.edu/~dball/

Batanero, C., Burrill, G., & Reading, C. (2011). *Teaching statistics in school mathematics - Challenges for teaching and teacher education: A Joint ICMI/IASE Study* (pp. 407-418). Dordrecht, The Netherlands: Springer.

Batanero, C., & Díaz, C. (2010). Training teachers to teach statistics: What can we learn from research? *Statistique et enseignement*, *1*(1), 5-20. Retrieved from http://statistique-etenseignement.fr/ojs/

Ben-Zvi, D. (2000). Towards understanding the role of technological tools in statistical learning. *Mathematical Thinking and Learning*, 2 (1&2), 127–155.

Burgess, T. A. (2006). A framework for examining teacher knowledge as used in action while teaching statistics. In A. Rossman & B. Chance (Eds.), *Working cooperatively in statistics education. Proceedings of the 7th International Conference on Teaching Statistics. Salvador, Brazil*: IASE and ISI. Online: www.stat.auckland.ac.nz/~iase/publications

Cobb P., Confrey, J., diSessa, A., Lehrer, R., & Schauble, L. (2003). Design Experiments in Educational Research. *Educational Researcher, 32*(1), 9-13.

Cobb, P., & McClain, K. (2004). Principles of instructional design for supporting the development of students' statistical reasoning. In D. Ben-Zvi & J. Garfield (Eds.), *The challenge of developing statistical literacy, reasoning, and thinking* (pp. 375–396). Dordrecht, The Netherlands: Kluwer Academic Publishers.

delMas, R. C. (2004). A comparison of mathematical and statistical reasoning. In J. Garfield & D. Ben-Zvi (Eds.), *The challenge of developing statistical literacy, reasoning, and thinking* (pp. 79–95). Dordrecht, The Netherlands: Kluwer.

Fitzallen, N., & Watson, J. (2010). Developing statistical reasoning facilitated by tinkerplots. In C. Reading (Ed.), *Data and context in statistics education: Towards an evidence-based society. Proceedings of the Eighth International Conference on Teaching Statistics (ICOTS8),* Ljubljana, Slovenia. Voorburg, The Netherlands: ISI.

Franklin, C., Kader, G., Mewborn, D., Moreno, J., Peck, R., Perry, M., & Scheaffer, R. (2007). *A curriculum framework for K-12 statistics education*, GAISE report, American Statistical Association. Retrieved from http://www.amstat.org/education/gaise/

Garfield, J., & Ben-Zvi, D. (2008). *Developing students' statistical reasoning: Connecting research and teaching practice*. Springer.

Groth, R. E. (2007). Toward a conceptualization of statistical knowledge for teaching. *Journal for Research in Mathematics Education*, *38*(5), 427–437.

Groth, R. E. (2013). Characterizing key developmental understandings and pedagogically powerful ideas within a statistical knowledge for teaching framework. *Mathematical Thinking and Learning*, *15*, 121–145.

Hill, H. C., Ball, D. L., & Schilling, S. G. (2008). Unpacking pedagogical content knowledge: Conceptualizing and measuring teachers' topic-specific knowledge of students. *Journal for Research in Mathematics Education*, *39*(4), 372–400.

Lee, H. S., & Hollebrands, K. (2008). Preparing to teach data analysis and probability with technology. In C. Batanero, G. Burrill, C. Reading, & A. Rossman (Eds.), *Joint ICMI/IASE study: Teaching statistics in school mathematics. Challenges for teaching and teacher education. Proceedings of the ICMI Study 18 and 2008 IASE Round Table Conference*. Monterrey, Mexico: ICMI and IASE. Online: www.stat.auckland.ac.nz/~iase/publications

Llinares, S., & Krainer, K. (2006). Mathematics (student) teachers and teacher educators as learners. In A. Guitierrez & P. Boero (Eds.), *Handbook of Research on the psychology of mathematics education: Past, present and future* (pp. 429-459). Rotterdam, The Netherlands: Sense Publishers.

Mishra, P., & Koehler, M. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, *108*(6), 1017–1054.

NCTM (2000), *Principles and standards for school mathematics*. Reston, VA: NCTM.

Oliveira, H., Henriques, A. C., & Ponte, J. P. (2012). Developing statistical literacy (DSL): Student learning and teacher education. In *Pre-proceedings of the 12th International Congress on Mathematical Education* (pp. 7469), Seoul, Korea.

Ponte, J. P. (2011). Preparing teachers to meet the challenges of statistics education. In C. Batanero, G. Burrill & C. Reading (Eds.), *Teaching statistics in school mathematics - Challenges for teaching and teacher education: A Joint ICMI/IASE Study (pp. 299-309)*. New York, NY: Springer.

Ponte, J. P., & Chapman, O. (2006). Mathematics teachers' knowledge and practices. In A. Gutierrez & P. Boero (Eds.), *Handbook of research on the psychology of mathematics education: Past, present and future* (pp. 461-494). Rotterdam, The Netherlands: Sense Publishers.

Ruthven, K., & Goodchild, S. (2008). Linking research with teaching: Towards synergy of scholarly and craft knowledge. In L. English (Ed.), *Handbook of international research in mathematics education* (2nd ed., pp. 565-592). New York, NY: Routledge.

Schön, D. (1983). *The reflective practitioner: How professionals think in action*. New York: Basic Books.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4–14.

Sowder, J. (2007). The mathematical education and development of teachers. In F. K. Lester (Ed.), *Second handbook of research on mathematics teaching and learning* (pp. 157–224). Charlotte, NC: Information Age.

Wild, C., & Pfannkuch, M. (1999), Statistical thinking in empirical enquiry. *International Statistical Review*, 67(3), 221-24.