NEXT STEPS IN STATISTICS EDUCATION: IDENTIFYING TEACHER PROFESSIONAL DEVELOPMENT NEEDS FOR TEACHING THE *DATA ANALYSIS* COMPONENT OF PRIMARY LEVEL MATHEMATICS[i]

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This study reveals the pedagogical decision making undertaken when designing instruction for primary level statistics. We report on the activity of five groups of preservice teachers when engaging in Lesson Study and identify the content and pedagogical content knowledge needed for teaching statistics. The research highlights the power of lesson study to reveal aspects of statistical reasoning that are drawn heavily upon in the teaching of statistics and identifies fundamental weaknesses in statistical understanding that may not be uncovered through standard methods of assessment. The paper concludes with suggestions for how we can better prepare teachers for implementing statistics curricula at the primary level.

INTRODUCTION

With the emergence of statistics as a focal area of study at primary level arises the concomitant need for teacher education and professional development experiences focusing on emerging concepts in statistics education. We find ourselves in the unique position that many teachers have not themselves experienced statistics as learners while many preservice teachers have not experienced the latest curricular reforms in statistics education. As a result, many preservice and practising teachers are expected to teach content they themselves have not been exposed to, to teach in ways they themselves have not been taught (i.e. statistical investigations), and to structure instructional experiences that emphasize concepts with which they are not familiar (i.e. a focus on distributions, inference etc.). Indeed, Lajoie and Romberg (1998) comment that statistical concepts may be as new a topic for teachers as for the students they teach and recommend that "teachers must be provided with appropriate preservice and in-service training that will give them the knowledge base they need to feel comfortable teaching about data and chance" (p. xv).

Through a mixed-methods design incorporating Lesson Study, a quantitative survey of statistical knowledge, and clinical interviews, this research study explores preservice teacher's understandings of statistical and pedagogical concepts underpinning the content of primary level statistics curricula. This paper addresses the outcomes of the *Lesson Study* (Fernandez & Yoshida, 2004; Lewis, 2002) component of the study and identifies areas of need to be addressed in preservice and in-service professional development contexts.

THEORETICAL BACKGROUND

The Mathematical Sciences Advisory Committee of the College Entrance Examination Board (1984-1985), in response to the absence of data analysis and statistics in primary level mathematics curricula, stated "perhaps no other topics in mathematics surround and affect our lives as much and yet are so poorly understood as statistics and probability". North American curriculum development bodies responded and in April 1989 the National Council of Teachers of Mathematics released its *Curriculum and Evaluation Standards for School Mathematics*, which incorporated a strand on data analysis and probability. In 1991, the American Statistical Association published *Guidelines for the Teaching of Statistics K-12* (Burrill, 1991). Other countries were also modifying curricula to include statistics education as an area of focus. The *National Curriculum of England* (Qualifications and Curriculum Authority, 1999) incorporated data handling as one of its four attainment targets at keys stages 2-4. Similarly, in Ireland, a critical new departure for mathematics education was the inclusion of data as a strand of study in the *Revised Curriculum* (DES, 1999).

The introduction of statistics education poses challenges for the preparation of primary teachers to teach this new content. A fundamental component of teacher education programs is ensuring that preservice teachers have knowledge of the content they are going to teach. Ball (1988) refers to this type of knowledge as *knowledge of mathematics*, knowledge described by Ma (1999) as *profound understanding of fundamental mathematics*. This 'knowledge' can be surprisingly multifaceted and draws upon both procedural and conceptual understandings of the content to be taught. Procedural understandings of concepts involve knowing *how to* (Hiebert & Lefevre, 1986) generate measures and construct graphs i.e. finding the mean of a set of 20 numbers. While procedural understandings are critical they need to be accompanied by conceptual understandings of *why* we use particular graphs/measures. Conceptual understanding involves an *integrated and functional understanding* of concepts (National Research Council, 2001, p.141) and might inform decisions about when the mean is a useful and valid measure.

While the majority of studies examining content knowledge have focused on school level learners, a number of studies have identified weaknesses in both undergraduate students' and preservice/practicing teachers' *content knowledge understandings* of primary level statistics. Problems have been identified with: the mean (Gfeller, Niess & Lederman, 1999; Leavy & O'Loughlin, 2006; Mevarech, 1983), median (Friel & Bright, 1998; Groth & Bergner, 2006), variability (Canada, 2004), and reasoning about distributions (Leavy, 2006; Makar & Confrey, 2002). These studies have found that while procedural knowledge is quite robust, shortcomings in conceptual knowledge have been demonstrated across all areas. Other studies have shifted emphasis from an examination of content knowledge to investigating the process of engaging in statistical investigations (Heaton & Michelson, 2002; Leavy, 2006; Makar & Confrey, 2002) but the study of the transfer of this knowledge from college contexts to classrooms needs greater attention.

The knowledge needed to teach statistics, or *pedagogical content knowledge* (Shulman, 1986), is an area that has received little attention. Pedagogical content knowledge extends beyond understanding the statistical content and concerns the knowledge needed to guide teachers in the presentation of ideas, the anticipation of student misconceptions, and in the selection of investigations/tasks that provide opportunities for the development of statistical reasoning. It is this type of knowledge that is key to facilitating teachers in the implementation of new statistics curricula as it informs decisions that impact classroom activity. Examining pedagogical content knowledge can be difficult as it involves examining knowledge use in practice – in other words, looking in classrooms. The move to looking in mathematics classrooms is ongoing through the utilization of methodologies such as lesson study (Lewis & Tsuchida, 1998; Stigler & Hiebert, 1999), teaching experiment methodology (McClain, 2002; Simon, 1995; Steffe & Thompson, 2000), and teacher-as-researcher models (Ball, 2000; Ball & Bass, 2000; Lampert, 1990). Lesson study is described by Fernandez (2002) as a 'powerful continuous-improvement agent' within the Japanese school system. Methodologically, Lesson Study fits the majority of criteria for scientific research, criteria established by the National Research Council (cited in Lewis et al., 2006).

Lesson Study is a Japanese form of professional development involving the design and observation of live lessons, called research lessons, by a group of classroom teachers. The lesson is designed by the teachers, one of whom agrees to teach the lesson while the others observe and collect data on learning and teaching as it unfolds during the lesson. The research lesson and data detailing observations are shared at a post-lesson colloquium. It is through observing preservice teachers whilst engaging in *Lesson Study* that we gain insights into the knowledge needed for teaching statistics and examine this knowledge use in the primary classroom.

RESEARCH QUESTION

This study investigates preservice teachers involved in the design and teaching of research lessons aimed at primary level statistics. The underlying question motivating the study is: What is the content and pedagogical content knowledge required for teaching primary level statistics?

CONTEXT AND METHOD

Participants

There were 24 participants in the study, all of whom were final year preservice primary teachers. Four of the participants were male and the mean age of the group was 20.88 years. Eight of the participants were studying mathematics to degree level and the remainder studying alternative liberal arts subjects. All participants had elected to enrol in a curriculum specialization in mathematics education and identified themselves as having performed very well in mathematics pedagogy courses, as feeling confident in teaching primary mathematics, and were taking the class due to positive associations with mathematics and the desire to improve their skills in teaching mathematics. Participants did not identify the strand of data handling as posing any difficulties for them and did not request any additional support in the teaching of this strand (they did, however, request support in other areas of mathematics education).

Data Collection and Analysis

Participants were organized into five groups, each of which focused on the teaching of a different statistical concept/idea. The research lessons focused on: the mode, the median, the mean, graphical representations and their ability to illuminate aspects of data, and examining distributional shape. These were identified as key statistical concepts common across international curricula.

Group were studied as they moved through each stage of the lesson study process. During phase 1, *the research and preparation of a study lesson*, groups were observed as they worked collaboratively to design their lesson. Artefacts arising from the collaborative planning were collected, for example the questions arising from these meetings and resources used to plan lessons. The detailed lesson plan arising from this phase was presented to the researcher and feedback on the lesson plan was provided. During phase 2, *the implementation phase*, the researcher observed the teaching of the research lesson in a local primary school. The researcher participated in phase 3, *reflection and improvement* of the research lesson, by meeting with the group immediately after the lesson was taught and listening to and providing feedback to the group on the outcomes of the lesson. Finally, the newly revised lesson which constituted the *second implementation* stage was examined by the researcher prior to the lesson being taught. Each group provided a written report on the process of lesson study and made an in-class presentation to the entire class.

PRELIMINARY RESULTS

Charting the landscape of statistics education

An initial data collection activity was the construction of a concept map; the purpose of concept map production was to help reveal understandings of relationships between concepts within the area of data handling. Within the concept map, the spatial arrangement of concepts, their proximity to each other, and connections between concepts, were used as indicators of the understandings of an individual. Analysis of concept maps revealed that participants knew the details of *what* you would teach in primary level statistics but demonstrated little understanding of *how* content within the area was interconnected or interrelated. In general, understandings of data handling concepts were instrumental and consisted of isolated ideas that were poorly connected to other ideas. For example, the *number of concepts* mentioned in the maps varied from 1-5 with half of the responses having no more than two concepts. This indicates poor understanding of how concepts within the discipline are organized and related to each other. No mention of *variability* or the ways in which to represent variability were made and neither was reference made to *data type* or its influence on the graphs we choose to represent data. The concept of *language* came up several times and may indicate participants' own difficulty with terminology.

Underestimating the complexity of statistical concepts

Participants considered the primary curriculum statistical content as uncomplicated and straightforward. In some instances this lack of awareness of the complexity of the material was deeply entrenched. For example, initial planning meetings of the median group did not explore the median as a statistical measure. Discussions were focused on classroom activities and on what children would be engaged in 'doing'. Observation and analysis of the lesson and post lesson debriefing indicated that participants did not engage with the statistical content – they spoke about successful and unsuccessful components of the lesson but focused predominantly on procedural aspects rather than a critique of the ways in which their own understandings of the median limited the ways in which they were able to teach. It seemed that the *possibility* of examining their own content knowledge was an option they were reluctant to consider.

In the final reports and presentations, many participants commented on their initial underestimation of the complexity of data handling concepts. In the graphical representations group participants stated that initially they were confident about their understanding of the content and their ability to teach the topic, however they stated that once they started planning the lesson they became aware that they were not as knowledgeable as they had thought. '*Initially, I was pleased that I had quite a good, solid understanding of the concepts involved in the lesson … I felt I would be capable of preparing a satisfactory lesson .. however my involvement in the lesson study revealed to me that my understanding of the concepts was not as clear as I first thought*' (Paul, LS presentation).

Prior understandings are not sufficient to support pedagogical decision making

All participants had covered elements of statistics in secondary school and many had completed a course in statistics at undergraduate level. Despite this, participants had not been exposed to several ideas central to the teaching of statistics at primary level. Ideas of distributional shape, landmarks and features of data, and graphs as revealing aspects of data, to name a few, were unfamiliar territory for preservice teachers.

The lesson study group focusing on distributional shape mentioned in their initial log that they had never considered distributional shape prior to the topic being discussed and admitted to being confused as to what the topic meant. It emerged that no one had engaged in reasoning about distributional shape prior to this study and neither had they been exposed to the language and terminology commonly associated with discussion of shape. Similarly, members of the graphical representations group demonstrated the knowledge necessary to construct graphs, understandings beyond the procedural construction were lacking. For example, difficulty discerning between graphs was evident – almost two hours of time was dedicated in their group trying to discern bar graphs from histograms. The following quote is from one member who comments on how group discussion during planning of the lesson helped reveal deficiencies in his own understandings relating to the teaching of graphs. *'I was not sure of the answers as we started asking question about what content to teach such as "Which graphs are suitable for displaying numerical data?" "Which graphs are suitable for showing categorical data?" "Which graphs will provide a stark contrast visually for the children?" "Which graphs show outliers, the mean, the mode, the median, and gaps in the data clearly?" The discussion we had based on these topics made me realize that there were significant gaps and deficiencies in my content knowledge regarding this topic'* (Amanda, LS report).

Classroom experiences act as a catalyst for unpacking (Ma, 1999) understandings and for seeking to further develop statistical understandings.

Some participants did not become fully aware of the complexity of the statistical concepts until they taught the lesson. The act of teaching data lessons and the questions posed by children revealed aspects and complexities of data concepts that were not apparent when planning the lesson. Enacting the lesson in the classroom revealed the multifaceted nature of the concepts being taught. For example, in the *mode* group a situation arose in which children's question posed during the lesson revealed aspects and subtleties of the mode that the group were oblivious to. As one group member stated in her reflective critique: '*After the first lesson, I realized just how hard a topic the mode is to teach. I found I didn't know the answers to the children's questions. I*

wasn't able to simplify the definitions for the children, as I probably didn't understand them myself' (Sínead, presentation).

IMPLICATIONS

Analysis of the data from the Lesson Study has lead to the formulation of suggestions for how we might better prepare teachers for implementing new statistics curricula at the primary level. Suggestions include the need to: (1) Structure professional development experiences that are situated within investigative contexts. Statistical investigations highlight the richness of decision making involved when engaging with data as opposed to the clinical contexts of textbook activities. (2) Engage teachers in working with messy data. This will give them experience making decisions that arise from working with real data (for example, deciding what to do when there are outliers, ascertaining the suitability of the data). (3) Design instruction for learners and build in opportunities to observe the effectiveness of these pedagogical activities. These experiences, similar to those in a lesson study cycle, allow teachers to focus on pedagogical decisions, emphasize concepts rather than procedures, and reveal content knowledge difficulties in the process. The presentation will also highlight specific misconceptions and difficulties related to primary level statistics.

REFERENCES

Ball, D.L. (1988). Unlearning to teach mathematics. *For the Learning of Mathematics, 8*(1), 40-48.

Ball, D.L., & Bass, H. (2000). Interweaving content and pedagogy in teaching and learning to teach: Knowing and using mathematics. In J. Boaler (Ed.), *Multiple Perspectives on Mathematics Teaching and Learning* (pp. 83-104). Westport, CT: Abex.

Ball, D. (2000). Working on the Inside: Using One's Own Practice as a Site for Studying Teaching and Learning. In E. Kelly & R. Lesh (Eds.), *The Handbook of Research Design in Mathematics and Science Education* (pp. 365-402). Mahwah, NJ: Lawrence Erlbaum.

Burrill, G. (Ed.) (1991). *Guidelines for the Teaching of Statistics.* American Statistical Association, Alexandria, Virginia, U.S.A.

Canada, D. (2004). *Preservice teachers' understanding of variation.* Unpublished doctoral dissertation, Portland State University, Portland, Oregon (USA). [Online: www.stat.auckland.ac.nz/~iase/publications/dissertations/dissertations.php]

Department for Education and Employment (DfEE) and Qualifications and Curriculum Authority (QCA) (1999). *The National Curriculum: Handbook for Primary Teachers in England*. London: HMSO.

Fernandez, C. (*2002*). Learning from Japanese approaches to professional development: The case of *lesson study*. Journal of Teacher Education, 53(5), 390-405.

Fernandez, C. & Yoshida, M. (2004). *Lesson Study. A Japanese Approach to Improving Mathematics Teaching and Learning.* Erlbaum: Mahwah, New Jersey.

Friel, S. N. and Bright, G. W. (1998). Teach-Stat: A Model for Professional Development in Data Analysis and Statistics for Teachers K-6. In S.P. Lajoie (Ed.), *Reflections on Statistics: Learning, Teaching, and Assessment in Grades K-12* (pp.299-316). Mahwah, NJ: Lawrence Erlbaum Associates.

Gfeller, M. K., Niess, M. L. & Lederman, N. G. (1999). Preservice Teachers' Use of Multiple Representations in Solving Arithmetic Mean Problems. *School Science and Mathematics, 99*(5), 250-257.

Groth, R.E. &, Bergner, J.A. (2006). Preservice Elementary Teachers' Conceptual and Procedural Knowledge of Mean, Median, and Mode. *Mathematical Thinking and Learning, 8*, 37-63.

Heaton, R. M., & Mickelson, W. T. (2002). The Learning and Teaching of Statistical Investigation in Teaching and Teacher Education. *Journal of Mathematics Teacher Education, 5*(1), 35-59.

Hiebert, J., & Lefevre, P. (1986). Conceptual and procedural knowledge in mathematics: An introductory analysis. In J. Hiebert (Ed.), *Conceptual and procedural knowledge: The case of mathematics* (pp. 1-27). Hillsdale, NJ: Lawrence Erlbaum Associates.

Lajoie, S. P., & Romberg, T. A. (1998). Identifying an agenda for statistics instruction and assessment in K–12. In S. P. Lajoie (Ed.), *Reflections on statistics: Learning, teaching, and assessment in grades K–12* (pp. vii–xxi). Mahwah, NJ: Lawrence Erlbaum Associates.

Lampert, M. (1990). When the problem is not the question and the solution is not the answer: Mathematical knowing and teaching. *American Education Research Journal, 1*, 29-63.

Leavy, A.M. (2006). Using data comparison to support a focus on distribution: Examining preservice teacher's understandings of distribution when engaged in statistical inquiry. *Statistics Education Research Journal, 5(*2), 89-114.

Leavy, A.M. & O'Loughlin, N. (2006). Moving Beyond the Arithmetic Average: Preservice Teachers Understanding of the Mean. *Journal of Mathematics Teacher Education, 9*(1), 53-90. .

Lewis, C. (2002). Lesson *Study: A handbook of teacher-led instructional improvement.* Philadelphia: Research for Better Schools.

Lewis, C., Perry, R. & Murata, A. (2006). How should research contribute to instructional improvement? The case of Lesson Study. *Educational Researcher, 35*(3), 3-14.

Lewis, C., & Tsuchida, I. (1998). A lesson is like a swiftly flowing river: How research lessons improve Japanese education. *American Educator, 22*(4), 12-17, 50-52.

Ma, L. (1999). *Knowing and Teaching Elementary Mathematics: Teachers' understanding of fundamental mathematics in China and the United States.* Mahwah, NJ: Erlbaum.

Makar, K., & Confrey, J. (2002). *Comparing Two Distributions: Investigating Secondary Teachers' Statistical Thinking.* Paper presented at the Sixth International Conference on Teaching Statistics, Cape Town, South Africa.

Mathematical Sciences Advisory Committee, 1984-1985. Academic preparation in mathematics: Teaching for transition from high school to college. Cited in: Beres, R.J. (1988). Statistics for College Bound Students: Are the Secondary Schools Responding? *School Science and Mathematics, 88*(3), 200-209.

McClain (2002). A methodology of classroom teaching experiments. In S. Goodchild & L. English (Eds.), *Researching Mathematics Classrooms: A Critical Examination of Methodology*. Westport, CT: Praeger.

Mevarech, Z. R. (1983). A deep structure model of students' statistical misconceptions. *Educational Studies in Mathematics*, 14, 415-429.

National Research Council. (2001). *Adding it up: Helping children learn mathematics*. J.Kilpatrick, J. Swafford, and B.Findell (Eds.). Mathematics Learning Study Committee, Center for Education, Division of Behavioral and Social Sciences and Education. Washington, DC: National Academy Press.

Shulman, L.S. (1986). Those Who Understand: Knowledge Growth in Teaching. *Educational Researcher, 15*(2), 4-14.

Simon, M.A. (1995). Reconstructing mathematics pedagogy from a constructivist perspective. *Journal for Research in Mathematics Education, 26*(2), 114-145.

Steffe, L.P., Thompson, P.W. (2000). Teaching Experiment Methodology: Underlying Principles and Essential Elements. In E. Kelly & R. Lesh (Eds.), *The Handbook of Research Design in Mathematics and Science Education* (pp. 267-306). Mahwah, NJ: Lawrence Erlbaum.

Stigler, J.W., & Hiebert, J. (1999). *The teaching gap*. Chapter 7. New York: Free Press.

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