TEACHING STATISTICS AT THE PRIMARY SCHOOL LEVEL: BELIEFS, AFFORDANCES, AND PEDAGOGICAL CONTENT KNOWLEDGE

Helen L. Chick and Robyn U. Pierce
University of Melbourne
chick@unimelb.edu.au

The degree to which statistics teaching focuses on rules or on critical thinking depends on teachers' perceptions of and knowledge of statistics, along with their pedagogical content knowledge. This paper reports findings from a brief study with 27 pre-service primary teachers. The teachers completed a survey and planned a lesson for a grade six class, based on a resource that offered rich data and opportunities for addressing issues of statistical literacy. The survey responses and teaching plans analysis reveal an ambivalent attitude towards statistics and an inability or unwillingness to engage deeply with the resource. Most teaching plans focused on correct graphs and rules for presentation or calculation of statistics but put little if any emphasis on understanding the data source or its implications. This simple task provided insight into the pre-service teachers' knowledge and perceptions, as well as their priorities for their students.

BACKGROUND

The growing recognition of the importance of statistics in everyday life and the concerns about "statistical literacy" (Wallman, 1993) have resulted in a greater focus on the statistics curriculum at school and the capacity of teachers to deal with that curriculum. Statistics is taught in schools for three key reasons: it is useful for daily life, has an instrumental role in other disciplines, and is important in developing critical reasoning. These reasons are frequently espoused to support the inclusion of statistics in school curricula, yet, as seen in the Australian state of Victoria, these recommendations may not always be addressed deeply. At primary (elementary) school level statistics is often reduced to frequency counts and bar graphs, with rules for calculating mean and range added later. Indeed, the local curriculum itself does not give strong and specific emphasis to interpreting, reading, critiquing, and questioning data (Victorian Curriculum and Assessment Authority, 2005). This provides a poor foundation for developing analytical and statistical literacy skills through secondary school, with the consequence that, as adults, students will not have the capacity to make sense of data in context or deduce or question claims made from data (cf. the Statistical Literacy Hierarchy discussed in Watson, 2006). These challenges highlight the need for teachers to have both statistical knowledge and pedagogical knowledge related to statistics education, so that they can incorporate the analytical aspects amongst the routine computational ones. As yet only limited research has been done to determine what knowledge teachers have and what they require.

In the broad field of mathematics education the role of pedagogical content knowledge (PCK; Shulman, 1986) in learning has received considerable attention in recent years. It is loosely defined as the knowledge needed to successfully teach a subject and requires not only content knowledge but knowledge of examples, explanations, models and representations, connections among topics, and so on. The successful teaching of statistics requires specific, appropriate PCK. This is obviously critical at all levels, but there are additional complexities at the primary (elementary) school level, where teachers' preparation for teaching statistics might be limited. Watson (2006, p. 272) writes: "Do teachers know what it is they know and do not know? … Do teachers have experience with materials and tasks that can enhance understanding? In many cases I suspect the answer to these questions is "no." Furthermore, teachers' approach to teaching statistics will be influenced by their personal beliefs about and attitude towards statistics.

Of particular concern is the capacity of teachers to recognise and take advantage of statistical situations that arise in everyday life and use them for teaching. Clearly instruction about routine processes—such as graphing and calculation of measures of central tendency—is important, but statistical literacy requires the capacity to critically examine and reason about real-world data. With so much data available in the media and other sources, teachers have the

 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.*

opportunity to bring this information into the classroom and use it in productive ways. The significant issues here are whether or not teachers are able to (a) recognise what concepts can be addressed through a particular data set, and (b) implement effective learning in the classroom with the data. The concept of affordances, originating with Gibson (1977) and adapted by Chick (2007), is useful here. Chick defined the term potential affordances as the opportunities that are inherent in a task, lesson, or example. Teachers may or may not recognise all the affordances that an example has; this will be a function of their content knowledge (e.g., do they recognise that a situation involves or can be used to discuss a particular content concept such as the median or choosing the most helpful measure of variability?) and their PCK (e.g., do they know how to bring out that concept in the classroom?). Their lessons can only reflect the affordances that are recognised and will be influenced by the level of PCK that can be brought to bear in implementing the lesson.

This paper reports on an investigation of pre-service primary teachers' attitudes, knowledge, conceptions and beliefs in relation to statistics education and examines their capacity to recognize and implement affordances offered by real-world statistical examples. The key research questions considered are:

1. What are pre-service primary teachers' attitudes and beliefs about statistics and its role in school mathematics? How do these affect their pedagogical approaches?
2. What basic PCK and competencies do teachers require to successfully teach statistics at primary school levels?
3. To what extent do pre-service primary school teachers recognize and cater to the need to develop students' statistical literacy?
4. What research instruments are useful for determining the statistical PCK held by pre-service primary teachers?

METHOD

With the above background in mind, we sought to design a task that would allow us to examine the ways in which pre-service primary teachers use real-world statistical data in their classrooms. We obtained some data about local water storage levels from the internet (Melbourne Water, 2007). These data included a table showing the capacity, current actual volume, percentage full, overnight change in volume, and 24-hour rainfall information for nine local water storage reservoirs. In addition, there was a line graph showing the total volume and "percentage full" information for the entire water system over the course of a year, for the past 11 years. A size-reduced copy of the data is included as Figure 1. The on-line version of the graph allowed one or more years to be displayed simultaneously, and students were shown this interactive version in class, whereas the printout given to them showed all 11 years' data as 11 lines on a single static graph as in Figure 1. This information was particularly topical because recent drought conditions have increased awareness of water storage levels in the community. The context is of considerable local importance, and it is reasonable to expect it to be familiar and of interest even to primary school students since the issue of water shortage and saving water is addressed daily by local media. We wanted to see what kind of a statistics lesson teachers might plan based on these data.

The participants were two classes (27 students) enrolled in a mathematics education course for pre-service primary school teachers. These pre-service teachers had already had more than three semesters of mathematics education courses, covering elementary-level content and pedagogy. They had considered aspects of chance and data in their first year, about ten months before this research was conducted and had looked at aspects of graph reading (including the framework "read", "read between", and "read beyond" (Curcio, 2001)), types of graphs, and measures of central tendency. The pre-service teachers were asked to imagine that they had been doing some work on 'the environment' with a Grade 6 class (typically 11-year-old students) and to plan a lesson to teach students some aspects of statistics data using the water data information. Before planning the lesson in pairs (generating 13 lesson plans for analysis), students individually identified some of the statistics data topics they felt could be addressed with the resource (i.e., the potential affordances of the data set), and noted some of the questions

they might ask the Grade 6 students to answer or consider. This class work was undertaken as part of a 110-minute workshop, and the pre-service teachers' written responses and lesson plans were collected for analysis. These data were supplemented by the use of the ten-item STARC-CHANCE Abbreviated Scale (SCAS) instrument (Garfield, 1996, cited in Gal, Ginsburg, & Schau, 1997), with a five point Likert scale to explore students' understanding, attitudes, and beliefs about statistics, including its relevance to functioning in society. A further seven questions were added, specifically related to teaching statistics at primary school and the students' background in mathematics. The students provided consent for their class work to be analysed as data for this study.

We used standard qualitative methods (specifically, content analysis) to analyse the pre-service teachers' responses to the lesson plan task and to their identification of affordances and suitable questions in the data. Straightforward quantitative analysis was carried out on the beliefs and attitudes data. Because of space constraints the analysis presented here is necessarily brief and impressionistic, with the main purpose being to highlight some significant issues.

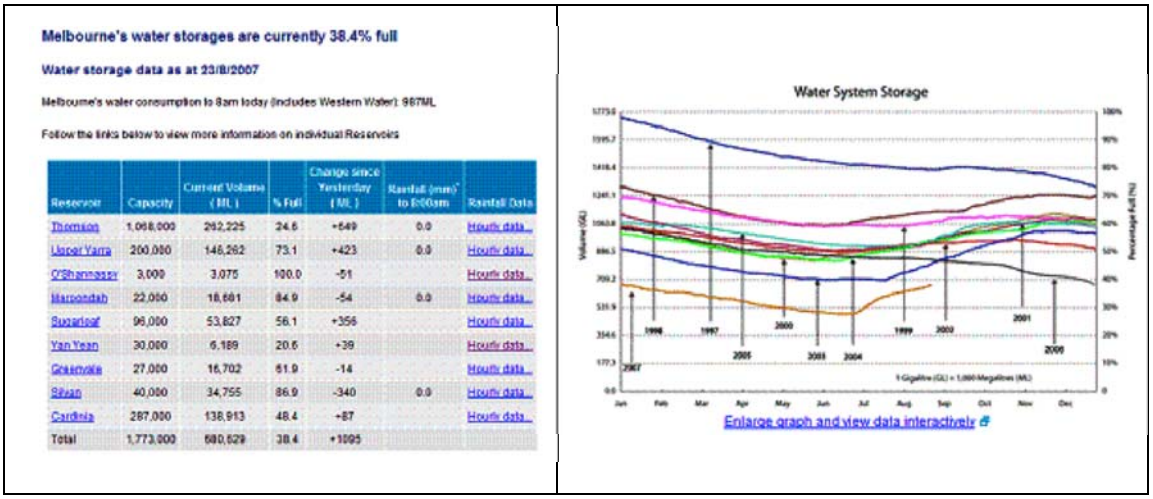

Figure 1. Melbourne water data used as a focus for the lesson plan task (Melbourne Water, 2007)

RESULTS

Beliefs and attitudes

Twenty-seven pre-service teachers provided responses to the survey items; of these, only 30% gave positive responses across all ten items, and there was only strong agreement from any student on two of the items. These were "To be an intelligent consumer, it is necessary to know something about statistics" (3 students) and, in contrast, "When buying a new car, asking a few friends about problems they have had with their cars is preferable to consulting an owner satisfaction survey in a consumer magazine" (4 students).

It is of concern—but consistent with their generally ambivalent responses—that 52% of pre-service teachers expressed either neutrality or agreement with the statement that "Because it is easy to lie with statistics, I don't trust them at all". Furthermore, 44% of the pre-service teachers disagreed with or chose the neutral option in response to the item "I feel I have sufficient knowledge statistics/'data' for teaching in primary school."

Affordances

Prior to working in pairs on the lesson-planning task the pre-service teachers completed four preliminary questions individually. One question asked them to identify statistics topics that could be addressed using the water data resource. All of the pre-service teachers identified some aspect of graphical work (interpreting or producing graphs), although in a few cases their descriptions were vague or potentially inappropriate (e.g., merely mentioning "graphing" or suggesting dot graphs, pie graphs, or box-and-whisker plots). Some of the more specific

graphical topics that were identified included reading graphs and tables (25%), interpreting graphs (25%), examining changes over time (25%), and comparing data (44%). Almost one third of the students mentioned mode, which is not useful, and although 62% of them wrote "averages", "mean" or "mean, median, and mode" (as if the phrase were a single concept), only one student explicitly identified a relevant context (mean capacity of the reservoirs). Over half the students listed "percentages" as a relevant topic, and one-third explicitly suggested "predictions" or "extrapolation".

The pre-service teachers were also asked to individually suggest questions that Grade 6 students could consider with respect to the supplied water data. Some of these questions involved reading the data directly or interpreting what was depicted by the graphical or tabular information (e.g., "How have water storage levels changed over time?", "What month has the greatest rainfall?", "What was the 'percentage full' value for a particular month?"). All but four of the 27 pre-service teachers (85%) identified such questions. In contrast, only 41% of them identified questions requiring students to reason beyond the data or consider implications. In some cases the questions required significant statistical interpretation ("Which months have the highest rainfall?", determined by looking at the changes in water storage volume over a number of years) and in others relied on more general knowledge ("Why does water storage vary?", "How can we save water?").

In examining the respondents' data, we attempted to quantify the relevant statistical emphasis evident in each topic identified and in each question. Thus, for example, "graph interpretation" received a higher score than "mean, median and mode", and "What year had the least percentage of water storage?" scored more than "Are we using more water today than yesterday?" This gave us a very coarse score for the statistical content value of each student's list of topics and proposed questions; there was, however, no correlation between these two quantities, so that successful identification of relevant statistical content did not necessarily indicate good choices of questions for students to consider or vice versa.

The most common feature of lesson plans was the intention to encourage class discussions and plan to have students to share their findings or graphs in small groups and with the whole class. These strategies are typical of approaches to teaching in the primary school in Australia. While they are certainly suitable pedagogical strategies, especially as vehicles for promoting statistical literacy, the efficacy will be only be maximised if the teacher has a clear idea of the important points that the discussion needs to address. In most of the lesson plans presented by these pre-service teachers the key concepts were not articulated. Instead there was a smattering of statistical terms and some recognition that some graphs are more useful or "correct" than others. We could not be confident from the written plans that class discussion would address analysis or interpretation of these data. One approach taken by six pairs (almost half of the students) was not to focus on the given data at all but to use the rainfall data situation as a spring-board to have their class collect and graph their own rainfall data, a risky strategy in times of drought. Although this provided students with an appropriate opportunity to learn about data gathering, there was little discussion of the statistical and mathematical learning outcomes from such an activity, and no connections were made between the data-gathering activity and the original water storage data presented on the web resource.

More generally, little emphasis was put on teaching students to engage with and interpret the data given, despite the request to use the resource for teaching some aspect of statistics. Only three of the 13 pairs presented lesson plans that involved sustained and effective use of the resource to bring out key statistical concepts. Two of the groups were careful to describe how to help students focus on each year's data in the graph, and then required students to focus on one particular month and examine how the storage levels for that month had changed over the eleven year period. These lesson plans brought out graphing issues, the idea of change over time, and, for one group, the calculation of average storage level for that particular month, with the second group considering predictions for the future instead. The third group focused on graph reading and interpretation, with some emphasis on percentage calculations and graph production. Not only did these lessons use the resource in a way that made good use of its affordances, but also the lessons were generally well planned and the concepts were clearly articulated.

Pedagogical Content Knowledge

It is acknowledged that written lesson plans cannot provide a full picture of a teacher's pedagogical content knowledge, as there are aspects that are more readily revealed in actual teaching practice. Nevertheless, an examination of the clarity and explicitness with which the concepts to be taught were expressed in the plans, the kinds of activities planned, and the pre-service teachers' acknowledgement of student understanding revealed much about their PCK. On a positive note, despite the fact that only three of the lessons used the resource in a deep and extended way, over half the pairs recognised the importance of helping students orient themselves to the data, thus demonstrating knowledge (a) of students' likely current levels of understanding and that attempts to teach new material must start from that point, (b) that data orientation is a significant concept to learn, and (c) that such ground-work is particularly difficult and important in this case. In contrast, four of the groups failed to be explicit about connections that needed to be made, notably the connection between work done in learning to read the given data and the later practical activity of collecting their own rainfall data. Similarly, in the cases where measures of central tendency were considered (seven groups), no attempt was made to discuss what calculations such as the mean actually reveal and how they relate to the data. Finally, and significantly, at least ten of the lesson plans mentioned concepts or ideas that were not clearly articulated, to the extent that the researchers could not be sure that the concept was going to brought out in a pedagogically appropriate and/or mathematically correct way.

DISCUSSION AND CONCLUSION

The neutral and negative responses of most of the pre-service teachers on the attitudes and beliefs scale suggest a general ambivalence towards statistics. Their lack of personal valuing of data was evident in their approaches to the lesson-planning task, in that they seemed to struggle to bring significant statistical concepts to the fore, despite all the affordances in the resource. Most of these pre-service teachers did not expect the students in their hypothetical Grade 6 class to seriously engage with the data provided by the resource. There is evidence here for the tendency, perhaps stronger among primary school teachers than their secondary counterparts, to choose active hands-on tasks but requiring only shallow thinking, at the expense of more conceptually challenging tasks that may not seem as "fun" in the classroom.

The lesson plans focused either on students having the experience of collecting their own data or on rules and details. These details included selection of "correct" graph types, following rules or procedures about scale and labelling graphs, reading values from graphs, or calculating percentages. Whereas these are all important concepts, the pre-service teachers' lesson plans did not demonstrate that these facts and skills would be presented in a connected fashion. Missing from many lesson plans were strategies to link the facts and skills and to apply these to some meaningful interpretation of the data in the resource.

While the SCAS instrument has proven useful in other contexts and is of some value in this study, future studies of teachers might provide richer data if the items were framed to more tightly target pre-service or practicing teachers. As it stands, the SCAS instrument deals with personal beliefs about statistics and its value but does not examine how teachers perceive the value of statistics as part of the curriculum or as something important for students and future participants in society to learn. In terms of examining teachers' capacity to identify affordances and their pedagogical content knowledge, the lesson-planning task seems to be a useful research tool. The preliminary requirements to identify (a) the concepts the resource seems to offer and (b) possible questions that students could consider allow teachers to indicate the concepts they perceive to be present and useable. This reveals aspects of both their level of statistical understanding and how statistics fits in the curriculum. The lesson plan itself can be used to examine strengths and weaknesses in a teacher's PCK, as it allows teachers to demonstrate whether or not they can bring out statistical ideas in ways that utilize the resource both effectively and with validity. Moreover, teachers' choices of tasks and questions reveal their priorities for content coverage. Further research using similar tasks for experienced teachers and

pre-service secondary teachers would be revealing and indicate important target issues for professional development.

This study has shown that, for primary teachers at least, more work needs to be done to help them develop the statistical and pedagogical content knowledge to identify what important concepts can be developed from a resource that uses real-world data. In terms of investigating these issues, however, the instruments used in the study seem to offer some promise. Furthermore, in addition to its role as a research instrument, the lesson-planning activity could be used as a teaching tool, to facilitate discussion and learning among pre-service and practicing teachers.

REFERENCES

Chick, H. L. (2007). Teaching and learning by example. In J. Watson & K. Beswick (Eds.), *Mathematics: Essential research, essential practice*. *Proceedings of the 30th annual conference of the Mathematics Education Research Group of Australasia* (pp. 3-21). Sydney: MERGA.

Curcio, F. (2001). *Developing data-graph comprehension in grades K-8* (2nd ed.). Reston, VA: National Council of Teachers of Mathematics.

Gal, I., Ginsburg, L., & Schau, C. (1997). Monitoring attitudes and beliefs in statistics education. In I. Gal & J. B. Garfield (Eds.), *The assessment challenge in statistics education* (pp 37-51). IOS Press.

Garfield, J. (1996). Assessing student learning in the context of evaluating a chance course. *Communications in Statistics. Theory and Methods, 25*(11), *2863-2873*.

Gibson, J. J. (1977). The theory of affordances. In R. Shaw & J. Bransford, (Eds.), *Perceiving, acting and knowing: Toward an ecological psychology* (pp. 67-82). Hillsdale, NJ: Lawrence Erlbaum.

Melbourne Water. (2007). *Water storages*. Website accessed on 23 August 2007. Online: www.melbournewater.com.au/content/water/water_storages/water_storages.asp

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

Victorian Curriculum and Assessment Authority. (2005). *Victorian Essential Learning Standards. Discipline-based Learning Strand: Mathematics*. Melbourne: Author.

Watson, J. M. (2006). *Statistical literacy at school: Growth and goals*. Mahwah, NJ: Lawrence Erlbaum.

Wallman, K. K. (1993). Enhancing statistical literacy: Enriching our society. *Journal of the American Statistical Association, 88*(421), 1-8.