PREPARING SCHOOL TEACHERS TO DEVELOP STUDENTS' STATISTICAL REASONING

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In this paper we discuss how two different types of professional development projects for school teachers are based on the same framework and are used to prepare knowledgeable and effective teachers of statistics. The first example involves a graduate course for masters' students in elementary mathematics education at the University of Haifa, Israel. The second example is a graduate course for in-service secondary mathematics teachers, at the University of Minnesota, USA. The framework used is based on six instructional design principles described by Cobb and McClain (2004). Our view of such a classroom is a learning environment for developing a deep and meaningful understanding of statistics and helping students develop their ability to think and reason statistically "Statistical Reasoning Learning Environment" (SRLE).

THE CHALLENGES INVOLVED IN PREPARING TEACHERS TO TEACH STATISTICS

Currently very few courses around the world are focused on the preparation of teachers of statistics, at any educational level. At the same time, new guidelines for teaching statistics at the K-12 and college level have been recently written, approved and disseminated (see The Guidelines for Assessment and Instruction in Statistics Education (GAISE); Franklin & Garfield, 2006), which pose challenges for novice or even experienced teachers. For the past several years the authors have each been teaching such a course, using many of the same activities, readings, and assignments. However, the teachers we with whom we work are quite different. One group consists of graduate students in mathematics education working on an advanced degree, at the University of Haifa (UH), in Israel. The other course is for non-degree seeking students, taken for professional development by secondary mathematics teachers at the University of Minnesota (UM), in the USA.

In each course, we strive to help the preservice and inservice teachers understand and appreciate the importance of statistics and develop into competent and effective teachers of this subject. One of our goals is to model for them what an effective and positive statistics classroom is like. Our view of such a classroom is a learning environment for developing a deep and meaningful understanding of statistics and helping students develop their ability to think and reason statistically. We call this type of classroom the "Statistical Reasoning Learning Environment" (SRLE) (see Garfield & Ben-Zvi, in press). By calling it a learning environment, we emphasize that it is more than a textbook, activities, or assignments that we provide to our students. It is the combination of text materials, class activities and culture, discussion, technology, teaching approach, and assessment. Our model is based on six principles of instructional design described by Cobb and McClain (2004). We use these principles to design and teach our course and also explicitly teach these principles to our students as they prepare to become teachers of statistics. These principles are:

1. Focus on developing central statistical ideas rather than on presenting set of tools and procedures.
2. Use real and motivating data sets to engage students in making and testing conjectures.
3. Use classroom activities to support the development of students' reasoning.
4. Integrate the use of appropriate technological tools that allow students to test their conjectures, explore and analyze data, and develop their statistical reasoning.
5. Promote classroom discourse that includes statistical arguments and sustained exchanges that focus on significant statistical ideas.
6. Use assessment to learn what students know and to monitor the development of their statistical learning as well as to evaluate instructional plans and progress.

DESIGNING PROFESSIONAL DEVELOPMENT COURSES BASED ON THIS FRAMEWORK

We now elaborate on how our courses are built on this framework.

1. Focus on Developing Central Statistical Ideas (Content)

We introduce several key statistical ideas to the teachers in our classes as the important ideas we would like students to understand at a deep conceptual level. These ideas have been studied in the research literature, and our students investigate what has been learned about developing these ideas as we have them read a sample of the literature and experience activities that develop these concepts. The big ideas include:

- *Data*: Understanding the need for data in making decisions and evaluating information, the different types of data, how the methods of collecting data (via surveys) and producing data (in experiments) make a difference in the types of conclusions that can be drawn, knowing the characteristics of good data and how to avoid bias and measurement error. Understanding the role, importance of and distinction between random sampling and random assignment in collecting and producing data.
- *Distribution*: Understanding that a set of data may be examined and explored as an entity (a distribution) rather than as a set of separate cases, that a graph of these (quantitative) data can be summarized in terms of shape, center, and spread; that different representations of the same data set may reveal different aspects of the distribution; that visually examining distributions is an important and necessary part of data analysis, and that distributions may be formed from sets of individual data values or from summary statistics such as means (e.g., sampling distributions of means). Distributions also allow us to make inferences by comparing an obtained sample statistic to a distribution of all possible sample statistics for a particular theory or hypothesis.
- *Variability*: Understanding that data vary, sometimes in predictable ways. There may be sources of variability that can be recognized and used to explain the variability. Sometimes the variability is due to random sampling or measurement error. Other times, it is due the inherent properties of what is measured (e.g., weights of four year olds). An important part of examining data is to determine how spread out the data are in a distribution. It is usually helpful to know a measure of center when interpreting measures of variability, and the choice of these measures depends on the shape and other characteristics of the distribution. Different variability measures tell you different things about the distribution (e.g., standard deviation focuses on typical distance from the mean, range tells the difference between the minimum and maximum values, and IQR reveals the width of the middle half of the data) (Garfiel, & Ben-Zvi, 2005).
- *Center*: Understanding the idea of a center of a distribution as a “signal in a noisy process” (Konold & Pollatsek, 2002), which can be summarized by a statistical measure (such as mean and median). It is most helpful to interpret a measure of center along with a measure of spread, and these choices often are based on the shape of the distribution and whether or not there are other features such as outliers, clusters, gaps, and skewness.
- *Randomness*: Understanding that each outcome of a random event is unpredictable, yet we may predict long-term patterns. For example, we cannot predict if a roll of a fair die will be a 2, or any other number, but we can predict that over many rolls about 1/6 will be 2’s.
- *Covariation*: Understanding that the relationship between two quantitative variables may vary in a predictable way (e.g., high values with one variable tend to occur with high values of another). Sometimes this relationship can be modeled with a straight line (the regression line). This allows us to predict values of one variable using values of the other variable. An association does not necessarily imply causation, although there may be a causal relationship (a randomized comparative experiment is needed to determine cause and effect).

- *Sampling*: Understanding that much of statistical work involves taking random samples and using them to make estimates or decisions about the populations from which they are drawn. Samples drawn from a population vary in some predictable ways. We examine the variability within a sample as well as the variability between samples when making inferences.

2. Use Real and Motivating Data

Data are at the heart of statistical work, and we try to make data the focus for statistical learning as well. In our classes we examine many data sets as well as ideas for collecting data and consider how they may be used to motivate and engage students. Students are challenged to explore and learn from data in ways we would like them to. For example, teachers in the UH course examine data sets that can be gathered with young children, such as the number of lost milk teeth, or the distances students can jump. Teachers in the UM course discuss the merits of data that can be gathered on a first day of class survey of body measurements (arm span, hand span, head circumference) that can easily be gathered using a measuring tape. Both classes also discuss good sorts of data that can be gathered on the Internet (e.g., the CensusAtSchool project at www.censusatschool.org/; and Consortium for the Advancement of Undergraduate Statistics Education (CAUSE) at www.causeweb.org/).

3. Use Classroom Activities to Develop Students' Statistical Reasoning

An important part of the SRLE is the use of carefully designed activities that promote student learning through collaboration, interaction, discussion, data, and interesting and ill-structured problems (see Bransford, Brown, & Cocking, 2000). We discuss with our teachers the positive effects of active learning such as short-term mastery, long-term retention, depth of understanding of course material; acquisition of critical thinking or creative problem-posing and problem-solving skills; formation of positive attitudes toward the subject being taught, and level of confidence in knowledge or skills.

We draw the teachers' attention to two different models of class activities in the SRLE. The first engages students in making conjectures about a problem or a data set, as introduced in the preceding section on using real data. This method involves discussing students' conjectures, gathering or accessing the relevant data, using technology to test their conjectures, discussing the results, and then reflecting on their own actions and thoughts. The teachers experience such activities and then discuss their implementation in class and benefits and possible obstacles. An activity like this used with high school teachers is "can students in this class correctly identify Coke or Pepsi in a blind taste test?" With elementary teachers, they may use an activity such as: "Explore and compare the student backpack weights in relation to student body weights in all three divisions of our school."

The second type of activity is based on cooperative learning, where two or more students are given questions to discuss or an open problem to solve as a group. For example, secondary school students could be given an activity involving a Web applet for bivariate data where they are asked to figure out a rule describing how individual points that seem to be outliers may affect the correlation and fitting of a regression line for set of bivariate data (e.g., the Least Squares Regression and Guess the correlation applets in www.rossmanchance.com/applets/). They try different locations of a point, seeing the resulting effect on the correlation coefficient and regression line. Elementary teachers may be given a hands-on activity such as the "Stringing Students Along" activity (Shaughnessy & Chance, 2005, pp. 43-44). A bag of 25 different length strings is used for drawing several samples of ten strings with replacement to estimate the mean string length in the entire population. The students then discuss why this sampling method is biased (longer strings are more likely to be chosen) and suggest different, better sampling methods.

We try to help the teachers understand that when using cooperative learning activities, it is important that students work together as a group (and often in pairs using technology), not just compare their answers (Johnson, Johnson & Smith, 1998).

4. Integrate the Use of Appropriate Technological Tools

An important aspect of our courses is exposing the teachers to innovative technology tools that can be used to explore and simulate data, test conjectures by analyzing data, and develop abstract concepts. Teachers in the UH class mainly examine *TinkerPlots* (Konold & Miller, 2005; www.keypress.com/tinkerplots), a tool that allows students to build their own graphs and analyze data in ways that match their own intuitions.

Teachers in the UM class are also introduced to *TinkerPlots* as a tool that can help students "see" the data hidden by graphs such as histograms and boxplots. They are also given experience using *Fathom* software (Key Curriculum Press, 2006; www.keypress.com/fathom), a flexible tool that allows them to easily explore data, as well as graphing calculators, simulation software, and web applets. Teachers in both courses are provided reading and resources on technology (e.g., Chance, Ben-Zvi, Garfield & Medina, 2007) and are challenged to discuss the important ways technology may be incorporated into activities to enhance students' learning.

5. Promote Classroom Discourse

Another important goal for the teachers in our courses is to develop an appreciation for the value of classroom statistical discourse. This is different from teachers asking questions and students responding. The kind of discourse we promote is dialogue where students learn to question each other, respond to each other's questions as well as defend their answers and arguments. The use of good activities and technology allows for a new form of classroom discourse. Cobb and McClain (2004) describe the characteristics of effective classroom discourse in which statistical arguments explain why the way in which the data have been organized gives rise to insights into the phenomenon under investigation; students engage in sustained exchanges that focus on significant statistical ideas. We try to model ways to create a classroom climate where students feel safe expressing their views, even if they are tentative. This can be done if teachers encourage students to express their conjectures and ask other students to comment on these conjectures, allowing questions that begin with "What do you think" or "What would happen if" can lead to good class discussions.

6. Use Alternative Assessment

While many high stakes assessments rely on multiple choice tests that primarily assess computational skills and factual knowledge, teachers need to become knowledgeable about alternative methods of assessment that provide formative information useful in guiding students' learning. The elementary teachers at the UH and the secondary teachers at the UM learn about student projects as a form of authentic assessment. These projects vary in structure but typically allow students to pose or select a problem, gather or access appropriate data to answer the problem, analyze the data, and write up the results in a technical report and/or presentation. In many cases, projects allow students to collaborate with peers and professionals. Other forms of alternative assessment are also used to assess students' statistical literacy (e.g., critique a graph in a newspaper), their reasoning (e.g., write a meaningful short essay), or provide feedback to the instructor (e.g., minute papers). We point the teachers to good assessment resources such as the ARTIST Website (https://app.gen.umn.edu/artist/).

In both courses we make the case that students will value what the teacher assesses. Therefore assessments need to be aligned with learning goals. We encourage teachers to focus assessments on understanding key ideas and not just on skills, procedures, and computed answers. This should be done with formative assessments used during a course (e.g., quizzes, small projects, or observing and listening to students in class) as well as with summative evaluations (course grades). We also assess the teachers in the course using alternative methods. For example, the secondary teachers are asked to work in a collaborative group to develop a class lesson plan, find and analyze a good data set, and present to the class a web resource that they think would be a good one to promote student learning and explain why. The elementary teachers are asked to work in a collaborative group to design an activity for elementary students aimed at developing reasoning about one central statistical idea. They implement the activity in their class, collect assessment data and share and discuss it during one of the course lessons.

CHALLENGES TO TEACHERS

We teach our classes based on the six components of the SRLE framework, as a way to model for teachers an approach other than what they have experienced themselves in learning statistics. We believe it is important for the teachers to experience this type of learning environment when they are the learners, as a way to encourage them to use this same type of approach in their classrooms. We have found different challenges in the two courses. For example secondary teachers in the UM course are usually mathematics teachers and are used to viewing statistics as mathematics and teaching statistics in terms of computations and formulas. They need experience analyzing and exploring real and messy data and seeing that there are no single correct answers to most statistics problems. Sometimes these secondary mathematics teachers have initially seemed more comfortable presenting material to students and less comfortable with the types of open-ended problems and discussions that we promote. Elementary teachers in the UH class usually seem more comfortable with the inquiry-based pedagogical methods and less comfortable with the statistical content, because many have not studied statistics or even much advanced mathematics. Therefore, part of this course consists of helping the teachers understand the important big ideas of statistics and data analysis.

EVALUATION OF THE COURSES

We use several different methods to evaluate the impact of our courses. Data are gathered to help us explore a variety of learning outcomes, such as:

1. How well teachers are able to understand, integrate and apply their knowledge of teaching statistics.
2. How well teachers understand the field of statistics education and how statistics relates to and differs from mathematics education.
3. How much teachers feel they have learned in the class.
4. How satisfied they are with the course.

Evaluation information is gathered both informally and formally. For example, teachers in each course are asked to create lesson plans that show how they are able to integrate and apply their learning in designing an entire class session to help students learn an important concept. In a more informal method, the UH students are asked to self-reflect on their learning in a Wiki personal page soon after class, when their memories are still fresh (Ben-Zvi, 2007). They can write about their learning experiences, understandings, concerns and difficulties, activities they (dis-) liked or found more (or less) useful, or report on their group's work. These journal entries are a valuable resource for the students that help develop metacognitive abilities by reflecting on and monitoring his/her learning processes (Schoenfeld 1992).

At UM, a midterm feedback form is used as well as an end of course evaluation. Most informative are the reflection papers the teachers write throughout the course and particularly, their end of course teaching philosophy statement that usually document their integration of course learning goals. Despite the challenges in helping preservice and in-service teachers prepare to teach statistics, we have noticed many successes. Some of the secondary teachers who have enrolled in the course at the U of M have joined a local network of college statistics teachers in the Twin Cities who meet monthly to share teaching ideas and resources and discuss the teaching of statistics. Other secondary teachers have reported great success in introducing activities into their classes and encouraging their colleagues to also enroll in this class. Teachers at the UH have reported that as a result of their participation in the course they had begun to give prominence to the (frequently neglected before) Data and Chance strand in their teaching mathematics in elementary classes. Several of them have decided to join *the Connections* project – an ongoing development and research project (grades 4–6) that focuses on the study of students' emerging statistical reasoning and argumentation skills within an empirical statistical enquiry cycle (Ben-Zvi, Gil, & Apel, 2007). Their commitment and enthusiasm in this project are taken as part of the course success.

CONCLUSION

This paper has described the use of a framework to design and teach courses to preservice and in-service teachers in two different countries. We continue to evaluate and revise our classes as we teach them each year. We are even offering a new online version of the courses for secondary teachers at the UM to make it more accessible to teachers outside the local area, while in Haifa we continue developing the blended version of the course based on the Wiki technology. We hope more faculty will explore ways to develop courses for elementary and secondary teachers and encourage faculty to consider the six components of the frameworks that we have found to be successful in designing and teaching our courses.

REFERENCES

Ben-Zvi, D. (2007). Using Wiki to promote collaborative learning in statistics education. *Technology Innovations in Statistics Education, 1*(1). Online: repositories.cdlib.org/uclastat/cts/tise/.

Ben-Zvi, D., Gil, E., & Apel, N. (2007). What is hidden beyond the data? Helping young students to reason and argue about some wider universe. In D. Pratt & J. Ainley (Eds.), *Reasoning about informal inferential statistical reasoning: A collection of current research studies*. Proceedings of the Fifth International Research Forum on Statistical Reasoning, Thinking, and Literacy (SRTL-5), University of Warwick, UK, August, 2007.

Bransford, J., Brown, A. L., & Cocking, R. R. (Eds.) (2000). *How people learn: Brain, mind, experience, and school.* Washington, DC: National Academy Press.

Chance, B., Ben-Zvi, D., Garfield, J., & Medina, E. (2007). The role of technology in improving student learning of statistics. *Technology Innovations in Statistics Education Journal, 1*(1). Online: repositories.cdlib.org/uclastat/cts/tise/.

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.

Franklin, C., & Garfield, J. (2006). The Guidelines for Assessment and Instruction in Statistics Education *(*GAISE) project: Developing statistics education guidelines for pre K-12 and college courses. In G. F. Burrill, (Ed.), *Thinking and reasoning about data and chance: Sixty-eighth NCTM Yearbook* (pp. 345-375). Reston, VA: National Council of Teachers of Mathematics.

Garfield, J., & Ben-Zvi, D. (2005). A framework for teaching and assessing reasoning about variability. *Statistics Education Research Journal*, *4*(1), 92-99. Online: www.stat.auckland.ac.nz/~iase/serj/

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

Johnson, D. W., Johnson, R.T., & Smith, K.A. (1998). *Active learning: Cooperation in the college classroom* (2nd Ed.). Edina, MN: Interaction Book Co.

Key Curriculum Press (2006). *Fathom Dynamic Data™ Software* (Version 2.03) Emeryville, CA: Key Curriculum Press. Available: www.keypress.com/fathom

Konold, C., & Miller, C. D. (2005). *TinkerPlots: Dynamic Data Exploration* (Version 1.0) [Computer software]. Emeryville, CA: Key Curriculum Press. Available: www.keypress.com/tinkerplots.

Konold, C., & Pollatsek, A. (2002). Data analysis as the search for signals in noisy processes. *Journal for Research in Mathematics Education, 33*(4), 259-289.

Schoenfeld, A. H. (1992). Learning to think mathematically: Problem solving, metacognition, and sense-making in mathematics. In D. Grouws (Ed.), *Handbook for Research on Mathematics Teaching and Learning* (pp. 334-370). New York: MacMillan.

Shaughnessy J. M., & Chance, B. (2005). *Statistical questions from the classroom*. Reston, VA: National Council of Teachers of Mathematics.