THE PRACTICE OF STATISTICS AT SCHOOL: GROWING COLLABORATION ACROSS SECTORS

Jane Watson[1], Christine Franklin[2], & J. Michael Shaughnessy[3]
[1]University of Tasmania, Australia
[2]American Statistical Association, USA
[3]Portland State University
Jane.Watson@utas.edu.au

Just as the practice of statistics has changed over the past 40 years, so has the approach to statistics education at the school level. This paper reviews past and current contributions and collaborations from three groups that are helping to build the foundations during the school years for a generation of statistically literate young people with potential to continue to study and practice statistics after school. These groups are the National Council of Teachers of Mathematics, the American Statistical Association, and academics conducting research at the school level. The groups have in the past, and continue, to collaborate and facilitate the statistical experiences students have as they progress through school. This collaboration is intended to prepare students to enter a data-driven world.

INTRODUCTION: ORGANIZATIONS AND CURRICULUM

When the National Council of Teachers of Mathematics (NCTM) published its yearbook on *Teaching Statistics and Probability* (Shulte, 1981), most school students were experiencing a mathematics curriculum that only included the mean, as had been the case since the late 19th century (e.g., Smith, 1866). Because statistics was not included in school text books and curriculum documents, there was little incentive or opportunity for the growing field of mathematics education research to take an interest in the topic. In fact, some of the early educational research focused on the mean (e.g., Pollatsek, Lima, & Well, 1981). Since the mid-1980s, however, the Joint Committee of the NCTM and the American Statistical Association (ASA) has worked to support the implementation and expansion of the practice of statistics at the school level. It is interesting that in producing the *Quantitative Literacy (QL)* series of books (e.g., Landwehr & Watkins, 1986), the Joint Committee purposely chose a title not including statistics "because they anticipated public anxiety about the term *statistics*" (Steen, 2001, p. 5). Although quantitative literacy and numeracy continue to be broad areas of interest for the mathematics education community, the practice of statistics and statistical literacy came into their own with the NCTM's *Curriculum and Evaluation Standards for School Mathematics* (1989). Starting in kindergarten, and continuing throughout elementary and secondary schooling, the NCTM suggested students should

- collect, organize, and describe data;
- construct, read, and interpret displays of data;
- formulate and solve problems that involve collecting and analyzing data. (p. 54)

Toward the end of the document the purpose of these goals was made clear.

> Statistical data, summaries, and inferences appear more frequently in the work and everyday lives of people than any other form of mathematical analysis. It is therefore essential that all high school graduates acquire, at the appropriate level, the capabilities identified in this standard. This expectation will require that statistics be given a more prominent position in the high school curriculum. (p. 170)

With statistics in the NCTM *Standards*, more presentations and workshops on probability and statistics began to be included in NCTM Conferences. Coincidentally, in the same year as the NCTM published its *Standards* (1989), Moore and McCabe published the first edition of their famous undergraduate text, *Introduction to the Practice of Statistics* (1989). In their preface, they indicated their "intent to introduce readers to statistics as it is used in practice. Statistics in practice is concerned with gaining understanding from data; it is focused on problem-solving" (p. xi). These recognitions of the importance of statistics had great influence around the world, with countries such as Australia (Australian Education Council, 1991) and New Zealand (Ministry of Education, 1992) following the lead of the NCTM and including statistics in their national curricula.

In M. A. Sorto, A. White, & L. Guyot (Eds.), *Looking back, looking forward. Proceedings of the Tenth International Conference on Teaching Statistics (ICOTS10, July, 2018), Kyoto, Japan.* Voorburg, The Netherlands: International Statistical Institute. iase-web.org

EVOLUTION OF RESEARCH AND NCTM DOCUMENTS

The changes opened the opportunity for research at the school level. Shaughnessy's (1992) review revealed more research interest in probability understanding than statistics understanding, although this has changed in subsequent years. Research with a focus on statistics grew noticeably in the 1990s (e.g., Batanero, Estepa, Godino, & Green, 1996; Mokros & Russell, 1995; Watson, Collis, Callingham, & Moritz, 1995). Concurrently, the NCTM became aware of the assistance needed by teachers to implement the *Standards* and produced the *Addenda Series*. The series included activities on "making sense with data" in books for Grades K to 6, as well as three focused books (K-6, 5-8, and 9-12) (e.g., Zawojewski, 1991) with many contexts and suggestions for implementing the Statistics and Probability component of the curriculum.

By the time that the NCTM's *Principles and Standards for School Mathematics* (2000) appeared, researchers were reporting on many individual and collective aspects of the practice of statistics, including for example on the use of technology (e.g., Ben-Zvi, 2000), assessment (Garfield & Gal, 1997), data handling and analysis (Jones et al., 2000), modelling (Lehrer & Romberg, 1996; Lehrer & Schauble, 2000), average (Watson & Moritz, 1999b), sampling (Watson & Moritz, 2000), and beginning inference (Watson & Moritz, 1999a). While broadening its focus with principles on Equity, Teaching, Learning, Assessment, and Technology, the NCTM reinforced the ingredients of statistics from 1989 by stating that Data Analysis should enable students to

- formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them;
- select and use appropriate statistical methods to analyze data;
- develop and evaluate inferences and predictions that are based on data. (p. 48)

Rearranging the order of the dot points reinforced the practice of statistics as suggested by Wild and Pfannkuch (1999) from their analysis of the work of their applied statistician colleagues. They suggested the Pose, Plan, Data, Analyze, Conclusion (PPDAC) cycle, which could be repeated if required to answer a question more completely. Following the publication of the *Principles and Standards*, the NCTM again produced a series of books with activities for teachers—the *Navigations Series*—for implementing the curriculum, including six books from pre-Kindergarten to Grade 12 covering Data Analysis and Probability (e.g., Burrill, Franklin, Godbold, & Young, 2003).

Recognizing the continuing research contribution across the field of mathematics education, the NCTM collaborated with researchers to produce *A Research Companion* (Kilpatrick, Martin, & Schifter, 2003) to the *Principles and Standards* with significant chapters on statistics (Konold & Higgins, 2003) and probability (Shaughnessy, 2003). Linking research to the classroom was also one of the aims of the NCTM in its 2006 yearbook, *Thinking and Reasoning with Data and Chance* (Burrill, 2006) and many researchers contributed to the publication. The following year, again Shaughnessy (2007) reviewed and analyzed more recent significant contributions of researchers to the teaching and learning of statistics. The NCTM has continued to promote connections between research and teaching statistics with the publications of series that include recommendations for statistics for middle school and secondary mathematics teachers, including *Reasoning and Sense Making in Statistics and Probability* (Shaughnessy, Chance, & Kranendonk, 2009).

ASA CONTRIBUTIONS AT THE SCHOOL LEVEL

The ASA continued an interest in the school level begun with the *QL* Series by producing, with the support of the ASA/NCTM Joint Committee, the *Pre-K-12 Guidelines for Assessment and Instruction in Statistics Education (GAISE) Report* (Franklin et al., 2007). In *GAISE*, learning progressions were produced for three levels of schooling: Early Childhood and Elementary, Intermediate, and Secondary. The framework laid out at each level reflected the practice of statistics as statistical problem solving:

- Formulate Questions – Anticipating Variability;
- Collect Data – Acknowledging Variability;
- Analyze Data – Accounting of Variability;
- Interpret Results – Allowing for Variability.

By including Planning with Collect Data, *GAISE* reflected the PPDAC cycle. The ASA has been committed to building a structure for the practice of statistics that mandates statistics education at all school levels. It has devoted resources to the professional development of teachers and creating peer-reviewed materials that teachers and teacher educators can utilize in their classroom (e.g., the Statistics Education Web [STEW] online K-12 lesson plans: <www.amstat.org/ASA/Education/STEW/home.aspx>). The ASA considered the school level such a high priority that they followed the *GAISE* interest in the statistics curriculum with the *Statistical Education of Teachers (SET)* (Franklin et al., 2015), to provide objectives for pre-service and inservice training of teachers of statistics. They also recently created the K-12 Statistical Ambassador position to provide leadership in coordinating with other educational organizations and to advocate for statistics at the school level.

EVOLUTION OF STATISTICS EDUCATION JOURNALS AND BOOKS

Added to the interactions of the NCTM, the ASA, and statistics education researchers is the evolution of journals. Although the NCTM does not sponsor a journal specific to statistics education, its journals often publish reports about statistics education research in the *Journal for Research in Mathematics Education* (e.g., Noll & Shaughnessy, 2012; Watson & Moritz, 2000); or about topics of relevance on teaching statistics at all levels of schooling recognized by *GAISE* (Franklin et al., 2007) in *Teaching Children Mathematics (TCM)* (e.g., English, 2013), *Mathematics Teaching in the Middle School (MTMS)* (e.g., Watson & Shaughnessy, 2004) and *The Mathematics Teacher (MT)* (e.g., Scheaffer & Tabor, 2008; Strayer & Matuszewski, 2016).

The ASA has been publishing papers on education and teaching in the *Journal of Statistics Education (JSE)* since 1993. Although mainly focusing on the tertiary level, *JSE* has included reports on teacher education (e.g., Green & Blankenship, 2013) and classroom work with school students (e.g., Whitaker & Jacobbe, 2017). At times the breadth of *JSE* allows consideration of similar issues at the two levels; for example, Watkins, Bargagliotti, and Franklin (2014) discuss college students and Watson and English (2016) discuss Grade 5 students in relation to repeated sampling and prediction of the mean. Following many years publishing a newsletter, often focusing on articles of interest at the school level, the Joint Committee of the ASA and NCTM has now launched the *Statistics Teacher* (from 2016), an on-line journal aimed specifically at the school level, with ideas and resources for the classroom. It is expected that this latest collaboration will encourage researchers to tell of their classroom experiences for the benefit of other teachers.

The ASA's *SET* document (Franklin et al., 2015) is significant in adding a specific teaching perspective to the organization's interest in the school level, making suggestions for pre-service teacher education and providing examples of activities that satisfy its requirements. At the same time the NCTM has produced many books to assist teachers (e.g., Crites & St. Laurent, 2015; Kader & Jacobbe, 2013; Shaughnessy & Chance, 2005), including recognition of the *Common Core State Standards for Mathematics* (Common Core State Standards Initiative, 2010). Acknowledging the *Common Core*, which is recognized by many US states, is important but the *Common Core* does not include "Statistics and Probability" until Grade 6. Reflecting this emphasis, the latest series of NCTM books on *Reasoning and Sense Making* related to the *Common Core* includes a chapter on statistics and probability in its book for Grade 6 to 8 (Watson, 2017). The valuable contribution made by other NCTM and *GAISE* curriculum documents, starting with the early school years, is critical in developing the gradual approach that best suits children's learning.

EXAMPLES OF RESEARCH AT THE SCHOOL LEVEL

Research in statistics education has grown more rapidly since the 1990s, with detailed studies on various components of the practice of statistics, for example, variation (e.g., Reading & Shaughnessy, 2004), average (e.g., Makar, 2014), sampling (e.g., Watson & Kelly, 2005), distribution (e.g., Noll & Shaughnessy, 2012), and informal inference (e.g., Makar & Rubin, 2009). In the forthcoming *International Handbook of Research in Statistics Education* (Ben-Zvi, Makar, & Garfield, 2018) the title for the introductory chapter to the section on the major contributions of statistics education research uses Moore and McCabe's (1989) phrase "The practice of statistics." This focus has encouraged classroom research on statistical investigations employing the *GAISE* (Franklin et al., 2007) complete framework. Researchers in statistics education have also contributed to the field through their support of the International Association for Statistical Education (IASE) and in particular its *Statistics Education Research Journal* (SERJ).

A specific example of extended classroom research introducing the practice of statistics is provided by Watson and English (2015). In the study Grade 5 students undertook an investigation based on five items in the Australian Bureau of Statistics *CensusAtSchool* survey on environmental issues for the students or their families:

Our household has a water tank.
I take shorter showers. (4 mins max)
I turn the tap off while brushing my teeth.
I turn off appliances (e.g., TV, computer, gaming consoles) at the power point.
My household recycles rubbish.

The class answered the questions and recorded the percentage of "yes" responses for each question for the class. Students in pairs then decided the criteria to determine whether the class could be judged to be "environmentally friendly;" hence there were many criteria and decisions across the class. For the class as the population and the question "Are we environmentally friendly?", they could each make a decision. The question was then extended to "Are Grade 5 students in Australia environmentally friendly?" There was much discussion about the local climate, as well as the varying conditions across Australia and it was decided that their class was not a representative sample of all Grade 5s across the country. Each pair of students then took a random sample the size of their class from 1300 *CensusAtSchool* Grade 5 students' responses from across Australia. Again they made decisions for Australia, acknowledging more confidence in their decisions but not total certainty. Complete details of the students' capabilities and an extension to predict the "population" (1300) values based on more samples are given in Watson and English (2015, 2016).

CONCLUSION: CONTINUING POTENTIAL

The combination of the efforts of the NCTM, the ASA, and many researchers around the world, is providing a foundation for understanding of the practice of statistics before students leave high school. The ASA and NCTM are currently strengthening their collaboration to produce joint publications more easily, making statistical resources more readily available to school level teachers. The NCTM continues to support statistics as a major content strand in the school mathematics curriculum. The future of statistical literacy at the school level includes literacy to make sense of both traditional and non-traditional data. The *Pre-K-12 GAISE Framework* is currently being revised to reflect what school students need for understanding the practice of statistics in today's data-driven world. The hope is that some will go on with the practice, whereas others will have developed the experience to become statistically literate citizens. It can also be hoped that the model of collaboration provided by the NCTM, ASA, and researchers can be extended further with the potential for links to be created between the ASA and the IASE, and its journal, *SERJ*. Creating further connections among organizations and researchers will be a benefit for all.

REFERENCES

Australian Education Council. (1991). *A national statement on mathematics for Australian schools.* Melbourne: Author.

Batanero, C., Estepa, A., Godino, J.D., & Green, D.R. (1996). Intuitive strategies and preconceptions about association in contingency tables. *Journal for Research in Mathematics Education, 27,* 151-169.

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

Ben-Zvi, D., Makar, K., & Garfield, J. (Eds.). (2018). *International handbook of research in statistics education*. New York: Springer.

Burrill, G.F. (Ed.). (2006). *Thinking and reasoning with data and chance. Sixty-eighth yearbook*. Reston, VA: National Council of Teachers of Mathematics.

Burrill, G., Franklin, C.A., Godbold, L., & Young, L.J. (2003). *Navigating through data analysis in grades 9–12*. Reston, VA: National Council of Teachers of Mathematics.

Common Core State Standards Initiative. (2010). *Common Core State Standards for Mathematics*. Washington, DC: National Governors Association for Best Practices and the Council of Chief State School Officers. Retrieved from http://www.corestandards.org/assets/CCSSI_Math%20Standards.pdf

Crites, T., & St. Laurent, R. (2015). *Putting essential understanding of statistics into practice in grades 9-12*. Reston, VA: National Council of Teachers of Mathematics.
English, L. (2013). Surviving an avalanche of data. *Teaching Children Mathematics, 19*(6), 364-372.
Franklin, C., Bargagliotti, A., Case, C., Kader, G., Scheaffer, R., & Spangler, D. (2015). *Statistical education of teachers*. Alexandria, VA: American Statistical Association. Retrieved from http://www.amstat.org/education/SET/SET.pdf
Franklin, C., Kader, G., Mewborn, D., Moreno, J., Peck, R., Perry, M., & Scheaffer, R. (2007). *Guidelines for assessment and instruction in statistics education (GAISE) report: A preK-12 curriculum framework*. Alexandria, VA: American Statistical Association. Retrieved from http://www.amstat.org/education/gaise/
Garfield, J., & Gal, I. (1997). *The assessment challenge in statistics education*. Amsterdam: IOS Press and The International Statistical Institute.
Green, J.L., & Blankenship, E.E. (2013). Primarily statistics: Developing an introductory statistics course for pre-service elementary teachers. *Journal of Statistics Education, 21*(3). Retrieved from http://ww2.amstat.org/publications/jse/v21n3/green.pdf
Jones, G.A., Thornton, C.A., Langrall, C.W., Mooney, E.S., Perry, B., & Putt, I.J. (2000). A framework for characterizing children's statistical thinking. *Mathematical Thinking and Learning, 2*(4), 269-307.
Kader, G.D., & Jacobbe, T. (2013). *Developing essential understanding of statistics for teaching mathematics in grades 6-8*. Reston, VA: National Council of Teachers of Mathematics.
Kilpatrick, J., Martin, W.G., & Schifter, D. (Eds.). (2003). *A research companion to Principles and Standards for School Mathematics*. Reston, VA: National Council of Teachers of Mathematics.
Konold, C., & Higgins, T.L. (2003). Reasoning about data. In J. Kilpatrick, W.G. Martin, & D. Schifter, (Eds.), *A research companion to Principles and Standards for School Mathematics* (pp. 193-215). Reston, VA: National Council of Teachers of Mathematics.
Landwehr, J.M., & Watkins, A.E. (1986). *Exploring data: Quantitative literacy series.* Palo Alto, CA: Dale Seymour.
Lehrer, R., & Romberg, T. (1996). Exploring children's data modeling. *Cognition and Instruction, 14*(1), 69-108.
Lehrer, R., & Schauble, L. (2000). Inventing data structures for representational purposes: Elementary grade students' classification models. *Mathematical Thinking and Learning, 2*(1 & 2), 51-74.
Makar, K. (2014). Young children's explorations of average through informal inferential reasoning. *Educational Studies in Mathematics*, *86*(1), 61-78.
Makar, K., & Rubin, A. (2009). A framework for thinking about informal statistical inference. *Statistics Education Research Journal, 8*(1), 82-105.
Ministry of Education. (1992). *Mathematics in the New Zealand curriculum*. Wellington, NZ: Author.
Mokros, J., & Russell, S.J. (1995). Children's concepts of average and representativeness. *Journal for Research in Mathematics Education*, *26,* 20-39.
Moore, D.S., & McCabe, G.P. (1989). *Introduction to the practice of statistics*. New York: W.H. Freeman.
National Council of Teachers of Mathematics. (1989). *Curriculum and evaluation standards for school mathematics*. Reston, VA: Author.
National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics*. Reston, VA: Author.
Noll, J., & Shaughnessy, J.M. (2012). Aspects of students' reasoning about variation in empirical sampling distributions. *Journal for Research in Mathematics Education*, *43*, 509-556.
Pollatsek, A., Lima, S., & Well, A.D. (1981). Concept or computation: Students' understanding of the mean. *Educational Studies in Mathematics, 12,* 191-204.
Reading, C., & Shaughnessy, J. M. (2004). Reasoning about variation. In D. Ben-Zvi & J. Garfield (Eds.), *The challenge of developing statistical literacy, reasoning and thinking* (pp. 201-226). Dordrecht: Kluwer.

Scheaffer, R., & Tabor, J. (2008). Statistics in the high school mathematics curriculum: Building sound reasoning under uncertain conditions. *Mathematics Teacher*, *102*(1), 56-61.

Shaughnessy, J.M. (1992). Research in probability and statistics: Reflections and directions. In D.A. Grouws (Ed.), *Handbook of research on mathematics teaching and learning* (pp. 465-494). New York: National Council of Teachers of Mathematics & MacMillan.

Shaughnessy, J.M. (2003). Research on students' understandings of probability. In J. Kilpatrick, W.G. Martin, & D. Schifter (Eds.), *A research companion to Principles and Standards for School Mathematics* (pp. 216-226). Reston, VA: National Council of Teachers of Mathematics.

Shaughnessy, J.M. (2007). Research on statistics learning and reasoning. In F.K. Lester, Jr. (Ed.), *Second handbook on research on mathematics teaching and learning* (pp. 957-1009). Charlotte, NC: Information Age Publishing.

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

Shaughnessy, J.M., Chance, B., & Kronendonk, H. (2009). *Focus on secondary mathematics: Reasoning and sense making in statistics and probability*. Reston, VA: National Council of Teachers of Mathematics.

Shulte, A.P. (Ed.). (1981). *Teaching statistics and probability*. *1981 yearbook*. Reston, VA: National Council of Teachers of Mathematics.

Smith, B. (1866). *A shilling book of arithmetic for national and elementary schools*. Cambridge: Macmillan and Co.

Steen, L.A. (Ed.). (2001). *Mathematics and democracy: The case for quantitative literacy*. Washington, DC: Woodrow Wilson National Fellowship Foundation.

Strayer, J., & Matuszewski, A. (2016). Statistical literacy: Simulations with dolphins. *Mathematics Teacher*, *109*(8), 606-611.

Watkins, A.E., Bargagliotti, A., & Franklin, C. (2014). Simulation of the sampling distribution can mislead. *Journal of Statistics Education*, *22(*3). Retrieved from http://www.amstat.org/publications/jse/v22n3/watkins.pdf

Watson, J.M. (2017). Reasoning and sense making in statistics and probability. In M. Battista (Ed.), *Reasoning and sense making in grades 6–8* (pp. 73-112). Reston, VA: National Council of Teachers of Mathematics.

Watson, J.M., Collis, K.F., Callingham, R.A., & Moritz, J.B. (1995). A model for assessing higher order thinking in statistics. *Educational Research and Evaluation*, *1*, 247-275.

Watson, J., & English, L. (2015). Introducing the practice of statistics: Are we environmentally friendly? *Mathematics Education Research Journal*, *27*, 585-613. DOI 10.1007/s13394-015-0153-z

Watson, J., & English, L. (2016). Repeated random sampling in Year 5. *Journal of Statistics Education*, *24*(1), 27-37. DOI: 10.1080/10691898.2016.1158026

Watson, J.M., & Kelly, B.A. (2005). Cognition and instruction: Reasoning about bias in sampling. *Mathematics Education Research Journal*, *17*(1), 24-57.

Watson, J.M., & Moritz, J.B. (1999a). The beginning of statistical inference: Comparing two data sets. *Educational Studies in Mathematics*, *37*, 145-168.

Watson, J.M., & Moritz, J.B. (1999b). The development of concepts of average. *Focus on Learning Problems in Mathematics*, *21*(4), 15-39.

Watson, J.M., & Moritz, J.B. (2000). Developing concepts of sampling. *Journal for Research in Mathematics Education*, *31*, 44-70.

Watson, J.M., & Shaughnessy, J.M. (2004). Proportional reasoning: Lessons from research in data and chance. *Mathematics Teaching in the Middle School*, *10*, 104-109.

Whitaker, D., & Jacobbe, T. (2017). Students' understanding of bar graphs and histograms: Results from the LOCUS assessments. *Journal of Statistics Education*, *15*(2), 90-102. doi: 10.1080/10691898.2017.1321974

Wild, C., & Pfannkuch, M. (1999). Statistical thinking in empirical enquiry. *International Statistical Review*, *67*(3), 223-248.

Zawojewski, J.S. (1991). *Curriculum and evaluation standards for school mathematics Addenda Series, Grades 5-8: Dealing with data and chance*. Reston, VA: National Council of Teachers of Mathematics.