Teaching the Next Generation of Statistics Students to 'Think with Data': Special Issue on Statistics and the Undergraduate Curriculum

Nicholas J. Horton* and Johanna S. Hardin

Department of Mathematics and Statistics, Amherst College, Amherst, MA

Department of Mathematics, Pomona College, Claremont, CA

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*Address for correspondence: Department of Mathematics and Statistics, Amherst College, AC#2239, PO Box 5000, Amherst, MA 01002-5000. Phone: 413-542-5655, email: nhorton@amherst.edu

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This is an exciting time to be a statistician. The contribution of the discipline of statistics to scientific knowledge is widely recognized [McNutt, 2014] with increasingly positive public perception. Many feel “daunted by the challenge of extracting understanding from floods of disconnected data that threaten to swamp every discipline” [Yamamoto, 2013].

Demand for statisticians is strong, and it is frequently described as a top job [Wasserstein, 2015]. The McKinsey report [Manyika et al., 2011] makes clear the need for new graduates with “deep analytical skills,” and many (most?) of these new workers will be trained at the undergraduate level. Fortunately, the recent growth of undergraduate statistics programs is impressive. While still small in absolute numbers they have nearly doubled between 2010-2013 [Wasserstein, 2015] and are on track to continue to increase.

But there are challenges as well as opportunities in this new world of data [Ridgway, 2015, Horton, 2015]. The traditional statistics curriculum with mathematical foundations has not kept up with pressing demands for students who can make sense of data. Calls for transformed undergraduate education have resonated nationally [Holdren and Lander, 2012, Zorn et al., 2014]. These pressures led ASA President Nathaniel Schenker to convene an ASA workgroup to update the association’s guidelines for undergraduate programs. The group, with broad representation from academia, industry, and government, put forward guidelines that were endorsed by the ASA Board of Directors in November, 2014 [ASA, 2014]. Table 1 includes the full executive summary (a copy of the guidelines and related resources can be found at `http://www.amstat.org/education/curriculumguidelines.cfm`).

Much of the statistics education literature focuses on the introductory statistics course and statistics before college. Given the relatively few decades since the establishment of undergraduate statistics programs, this is not surprising. While there has been impressive growth in the number of students taking introductory statistics, there has been a relative dearth of articles on the curriculum beyond the introductory course. The 2014 ASA curriculum guidelines focus particular attention on the relationships between courses and student experiences beyond what has been implemented in traditional lecture courses. This issue of *The American Statistician* includes a set of papers that addresses the challenges and opportunities for undergraduate programs in statistics.

Many aspects of the revised guidelines are not new. As an example, consider the preface of the 1992 CATS workshop on “Modern Interdisciplinary University Statistics Education” that touches on a number of key aspects from the 2014 ASA guidelines (including graphics, communications, and applications) [CATS, 1994]:

> At its August 1992 meeting in Boston, the Committee on Applied and Theoretical Statistics (CATS) noted widespread sentiment in the statistical community that upper-level undergraduate and graduate curricula for statistics majors are currently structured in ways that do not provide sufficient exposure to modern statistical analysis, computational and graphical tools,

Executive Summary

The American Statistical Association endorses the value of undergraduate programs in statistics as a reflection of the increasing importance of the discipline. We expect statistics programs to provide sufficient background in the following core skill areas: statistical methods and theory, data management, computation, mathematical foundations, and statistical practice. Statistics programs should be flexible enough to prepare bachelor's graduates to either be functioning statisticians or go on to graduate school.

The widely cited McKinsey report states that "by 2018, the United States alone could face a shortage of 140,000 to 190,000 people with deep analytical skills as well as 1.5 million managers and analysts with the know-how to use the analysis of big data to make effective decisions" [Manyika et al., 2011]. A large number of those will be at the bachelor's level. The number of bachelor's graduates in statistics has increased by more than 140% since 2003 (21% from 2012 to 2013).

Much has changed since the previous guidelines were disseminated in 2000. The 2014 guidelines reflect changes in curriculum and suggested pedagogy. Institutions need to ensure that students entering the workforce or heading to graduate school have the appropriate capacity to "think with data" and to pose and answer statistical questions.

Key points include:

Increased importance of data science: Working with data requires extensive computing skills. To be prepared for statistics and data science careers, students need facility with professional statistical analysis software, the ability to access and manipulate data in various ways, and the ability to perform algorithmic problem-solving. In addition to more traditional mathematical and statistical skills, students should be fluent in higher-level programming languages and facile with database systems.

Real applications: Data should be a major component of statistics courses. Programs should emphasize concepts and approaches for working with complex data and provide experiences in designing studies and analyzing non-textbook data.

More diverse models and approaches: Students require exposure to and practice with a variety of predictive and explanatory models in addition to methods for model building and assessment. They must be able to understand issues of design, confounding, and bias. They need to be know how to apply their knowledge of theoretical foundations to the sound analysis of data.

Ability to communicate: Students need to be able to communicate complex statistical methods in basic terms to managers and other audiences and to visualize results in an accessible manner. They must have a clear understanding of ethical standards. Programs should provide multiple opportunities to practice and refine these statistical practice skills.

These guidelines are intended to be flexible while ensuring that programs provide students with the appropriate background along with necessary critical thinking and problem-solving skills to thrive in our increasingly data-centric world. Programs are encouraged to be creative with their curriculum to provide a synthesis of theory, methods, computation, and applications.

Table 1: Executive Summary—ASA Guidelines for Undergraduate Programs in Statistical Science (endorsed by the Board of Directors, November 2014)

> communication skills, and the ever growing interdisciplinary uses of statistics. Approaches and materials once considered standard are being rethought. The growth that statistics has undergone is often not reflected in the education that future statisticians receive. There is a need to incorporate more meaningfully into the curriculum the computational and graphical tools that are today so important to many professional statisticians. There is a need for improved training of statistics students in written and oral communication skills, which are crucial for effective interaction with scientists and policy makers. More realistic experience is needed in various application areas for which statistics is now a key to further progress. [CATS, 1994, vii]

We heartily concur. We also agree with Jon Kettenring's advice [CATS, 1994, 5-9] that "Industry needs holistic statisticians who are nimble problem solvers." The idea that an undergraduate statistics major develops general problem solving skills to use data to make sense of the world is powerful. We are concerned that many of our graduates do not have sufficient skills to be effective in the modern workforce. Thomas Lumley (personal communication) has stated that our students know how to deal with $n \to \infty$, but cannot deal with a million observations. If statistics is the science of learning from data, then our students need to be able to "think with data" (as Diane Lambert of Google has so elegantly described).

Likely the first and most important place to start the curricular conversation is with the courses that follow an introductory statistics course. For many years, the "second course" has been often been thought to be synonymous with regression. But even in 2000, Tarpey encouraged thinking outside the box for the applied regression and theoretical statistics courses:

> Statistical theory has most commonly been taught in the second semester of a year long sequence in probability and mathematical statistics. While that course is not unacceptable, the usual version is neither representative of modern statistical practice nor a good introduction to statistical thinking, and we encourage alternatives. For example, the applied regression and theory courses might be replaced by a two-semester sequence combining theory and applications. [Tarpey et al., 2000]

Do our bachelor's graduates have the needed skills to compute with data in the manner described by Nolan and Temple Lang [Nolan and Temple Lang, 2010, Nolan and Temple Lang, 2015]? Knowledge of a variety of statistical methods along with the ability to assess their potential and limitations is useful, but if an analyst can't wrangle data in a form to answer a statistical question, their utility may be limited. Our curricula need to prepare students to be able to fully engage in the entire data analysis process. The value that statistics brings to this enterprise needs to be highlighted and communicated, while other skills and capacities are added to our programs.

We note George Cobb's apt metaphor [Cobb, 2015] comparing changing curriculum to moving a graveyard: this squares with our experiences. We also agree that "Our territory—thinking with and about data—is too valuable to allow old curricular structures to continue to sit contentedly on their aging assets while more vigorous neighbors take advantage of the latest ideas." [Cobb, 2015, 5]. How do we ensure that our students have the useful skills to make their way? How do we ensure that they have flexible problem solving skills to tackle future problems using data with techniques and technology that may not yet exist?

The work of the ASA undergraduate guidelines working group (and the team that drafted the original ASA guidelines in 2000) leveraged a number of papers and resources that have helped to define the undergraduate statistics curriculum. Table 2 includes a selected set of papers (many published in *The American Statistician*) that are particularly noteworthy or groundbreaking. Readers are encouraged to familiarize themselves with these papers as part of ongoing curricular review.

Overview	
[Pierie, 1986]	Guidelines for bachelor degree curricula in statistics: An interim report
[Moore et al., 1995]	Statistics education fin de siècle
[Wild and Pfannkuch, 1999]	Statistical thinking in empirical enquiry
[Tarpey et al., 2000]	Curriculum guidelines for bachelor of arts degrees in statistical science
[Bryce et al., 2000]	Curriculum guidelines for bachelor of science degrees in statistical science
[Breiman, 2001]	Statistical modeling: the two cultures
[Moore, 2001]	Undergraduate programs and the future of academic statistics
[Ritter et al., 2001]	Advice from prospective employers on training BS statisticians
[Cannon et al., 2002]	Guidelines for undergraduate minors and concentrations in statistical science
[Scheaffer and Stasny, 2004]	The state of undergraduate education in statistics: A report from the CBMS 2000
[DeVeaux and Velleman, 2008]	Math is music: Statistics is literature
[Brown and Kass, 2009]	What is statistics?
[Nolan and Temple Lang, 2010]	Computing in the statistics curriculum
[Blair et al., 2010]	Statistical abstract of undergraduate programs in the mathematical sciences in the United States: Fall 2010 CBMS survey
[Cobb, 2011]	Teaching statistics: some important tensions
[Bailer et al., 2012]	Report on the ASA workgroup on master's degrees
[Johnstone, 2014]	Where are the majors?
[Utts, 2015]	The many facets of statistics education: 175 years of common themes
[Horton, 2015]	Challenges and opportunities for statistics and statistical education: Looking back, looking forward
[Wild, 2015]	On locating statistics in the world of finding out

[Saxe et al., 2015]	A common vision for undergraduate mathematical science programs in 2025
[ASA, 2015]	The statistical education of teachers
[Cobb, 2015]*	Mere renovation is too little too late: We need to rethink our undergraduate curriculum from the ground up
Computation and algorithmic thinking	
[CATS, 1994]	Modern interdisciplinary university statistics education
[Biehler, 1997]	Software for learning and for doing statistics
[Zhu et al., 2013]	Data acquisition and preprocessing in studies on humans: What is not taught in statistics classes?
[Wickham, 2014]	Tidy data
[Horton et al., 2015]	Setting the stage for data science: integration of data management skills in introductory and second courses in statistics
[Chamandy et al., 2015]*	Teaching statistics at Google scale
Data science	
[Cleveland, 2001]	Data science: An action plan for expanding the technical areas of the field of statistics
[Finzer, 2013]	The data science education dilemma
[Spiegelhalter, 2014]	The future lies in uncertainty
[Harville, 2014]	The need for more emphasis on prediction: A 'nondenominational' model-based approach
[Madigan and Wasserstein, 2014]	Statistics and science: A report of the London workshop on the future of the statistical sciences
[Ridgway, 2015]	Implications of the data revolution for statistics education
[Nolan and Temple Lang, 2015]	Data science in R: A case studies approach to computational reasoning and problem solving
[Baumer, 2015]*	A data science course for undergraduates: Thinking with data
[Hardin et al., 2015]*	Data science in statistics curricula: Preparing students to "Think with Data"
[Khachatryan, 2015]*	Incorporating statistical consulting case studies in introductory time series courses
[Leman, 2015]*	Developing a new interdisciplinary computational analytics undergraduate program: A Qualitative-Quantitative-Qualitative approach
Visualization and multivariate thinking	
[Friendly, 2008]	The golden age of statistical graphics
[Nolan and Temple Lang, 2009]	Approaches to broadening the statistics curricula

[Gould, 2010]	Statistics and the modern student
[Grolemund and Wickham, 2014]	A cognitive interpretation of data analysis
[Nolan and Perrett, 2015]	Teaching and learning data visualization: ideas and assignments
[Wagaman, 2015]	Meeting student needs for multivariate data analysis: a case study in teaching a multivariate data analysis course with no prerequisites
Second courses	
[Mosteller and Tukey, 1977]	Data analysis and regression: a second course
[Fecso et al., 1996]	Teaching survey sampling
[Kolenikov, 2015]	Training for the modern survey statistician
[Blades, 2015]*	The second course in statistics: Design and analysis of experiments
[Grimshaw, 2015]*	A framework for infusing authentic data experiences within statistics courses
[Sturdivant and Kuiper, 2015]*	Using online game-based simulations to strengthen students' understanding of practical statistical issues in real-world data analysis
Assessment	
[Hogg, 1999]	Let's use CQI in our statistics programs
[Garfield, 1994]	Beyond testing and grading: Using assessment to improve student learning
[Garfield et al., 2011]	Rethinking assessment of student learning in statistics courses
[ASA, 2005]	Guidelines for assessment and instruction in statistics education college report
[Starnes, 2015]	The AP Statistics exam: An insider's guide to its distinctive features
[Chance and Peck, 2015]*	From curriculum guidelines to learning outcomes: Assessment at the program level
[Kaplan, 2015]*	Program assessment for an undergraduate statistics major
Resampling	
[Cobb, 2007]	The Introductory Statistics Course: A Ptolemaic curriculum?
[Hesterberg, 2015]*	What teachers should know about the bootstrap: Resampling in the undergraduate statistics curriculum
[Tintle et al., 2015]*	Combating anti-statistical thinking using simulation-based methods throughout the undergraduate curriculum
[Wild et al., 2016]	Accessible conceptions of statistical inference: Pulling ourselves up by the bootstraps

Communication, capstones, and statistical practice	
[Higgins, 1999]	Nonmathematical statistics: A new direction for the undergraduate discipline
[COPE, 1999]	Ethical guidelines for statistical practice
[Lazar et al., 2011]	A capstone course for undergraduate statistics majors
[Fi and Degner, 2012]	Teaching through problem solving
[Çetinkaya Rundel and Stangl, 2013]	A celebration of data
[Cohen, 2014]	Ethics for undergraduates
[Bryce, 2015]	Developing tomorrow's statisticians
[Stodden, 2015]	Reproducing statistical results
[Nolan, 2015]*	Explorations in statistics research: An approach to expose undergraduates to authentic data analysis
[Smucker, 2015]*	Beyond normal: Preparing undergraduates for the work force in a statistical consulting capstone
Theoretical statistics	
[Nolan and Speed, 1999]	Teaching statistics theory through applications
[Nolan and Speed, 2000]	Stat labs: Mathematical statistics through applications
[Reid et al., 2003]	Is the Math Stat course obsolete?
[Horton et al., 2004]	Use of R as a toolbox for mathematical statistics exploration
[Chihara and Hesterberg, 2011]	Mathematical statistics with resampling and R
[Horton, 2013]	I hear, I forget. I do, I understand: a modified Moore-method mathematical statistics course
[Blankenship and Green, 2015]*	Fostering conceptual understanding in mathematical statistics

Table 2: Key papers on statistics in the undergraduate curriculum
(* denotes in this issue)

In this issue, we have assembled a set of papers that help describe a way forward. This includes a provocative paper by George Cobb that is accompanied by an online supplement with nineteen responses to the paper from an international group of statisticians (along with Cobb's rejoinder).

We hope that this collection of papers as well as the online discussion provide useful fodder for further review, assessment, and continuous improvement of the undergraduate statistics curriculum that will allow the next generation to take a leadership role by making decisions using data in the increasingly complex world that they will inhabit.

Acknowledgements

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References

[ASA, 2005] ASA (2005). Guidelines for assessment and instruction in statistics education college report. http://www.amstat.org/education/gaise.

[ASA, 2014] ASA (2014). 2014 curriculum guidelines for undergraduate programs in statistical science. http://www.amstat.org/education/curriculumguidelines.cfm.

[ASA, 2015] ASA (2015). The statistical education of teachers. http://www.amstat.org/education/SET.

[Bailer et al., 2012] Bailer, J., Hoerl, R., Madigan, D., Montaquila, J., and Wright, T. (2012). Report on the ASA workgroup on master's degrees. http://magazine.amstat.org/blog/2013/02/01/mastersworkgrou.

[Baumer, 2015] Baumer, B. (2015). A data science course for undergraduates: Thinking with data. *The American Statistician*.

[Biehler, 1997] Biehler, R. (1997). Software for learning and for doing statistics. *International Statistical Review*, 65:167–189.

[Blades, 2015] Blades, N. (2015). The second course in statistics: Design and analysis of experiments. *The American Statistician*.

[Blair et al., 2010] Blair, R., Kirkman, E. E., and Maxwell, J. W. (2010). Statistical abstract of undergraduate programs in the mathematical sciences in the United States: Fall 2010 CBMS survey. http://www.ams.org/profession/data/cbms-survey/cbms2010-Report.pdf.

[Blankenship and Green, 2015] Blankenship, E. and Green, J. (2015). Fostering conceptual understanding in mathematical statistics. *The American Statistician*.

[Breiman, 2001] Breiman, L. (2001). Statistical modeling: the two cultures. *Statistical Science*, 16:199–231.

[Brown and Kass, 2009] Brown, E. N. and Kass, R. E. (2009). What is statistics? *The American Statistician*, 63(2):105–110.

[Bryce et al., 2000] Bryce, G., Gould, R., Notz, W., and Peck, R. (2000). Curriculum guidelines for bachelor of science degrees in statistical science. http://www.amstat.org/education/pdfs/BS-curriculum.pdf.

[Bryce, 2015] Bryce, G. R. (2015). Developing tomorrow's statisticians. *Journal of Statistics Education*, 13.

[Cannon et al., 2002] Cannon, A., Hartlaub, B., Lock, R., Notz, W., and Parker, M. (2002). Guidelines for undergraduate minors and concentrations in statistical science. *Journal of Statistics Education*, 10.

[CATS, 1994] CATS (1994). Modern interdisciplinary university statistics education. In *Committee on Applied and Theoretical Statistics Proceedings of a Symposium*.

[Çetinkaya Rundel and Stangl, 2013] Çetinkaya Rundel, M. and Stangl, D. (2013). A celebration of data. *Chance*, 26(3).

[Chamandy et al., 2015] Chamandy, N., Muralidharan, O., and Wager, S. (2015). Teaching statistics at Google scale. *The American Statistician*.

[Chance and Peck, 2015] Chance, B. and Peck, R. (2015). From curriculum guidelines to learning outcomes: Assessment at the program level. *The American Statistician*.

[Chihara and Hesterberg, 2011] Chihara, L. M. and Hesterberg, T. C. (2011). *Mathematical Statistics with Resampling and R*. Wiley.

[Cleveland, 2001] Cleveland, W. S. (2001). Data science: an action plan for expanding the technical areas of the field of statistics. *International Statistical Review*, 69:21–26.

[Cobb, 2007] Cobb, G. (2007). The introductory statistics course: A Ptolemaic curriculum? *Technology Innovations in Statistics Education*, 1(1).

[Cobb, 2011] Cobb, G. W. (2011). Teaching statistics: some important tensions. *Chilean Journal of Statistics*, 2:31–62.

[Cobb, 2015] Cobb, G. W. (2015). Mere renovation is too little too late: We need to rethink the undergraduate curriculum from the ground up. *The American Statistician*.

[Cohen, 2014] Cohen, S. (2014). Ethics for undergraduates. http://www.amstat.org/education/pdfs/EthicsUndergraduates.pd

[COPE, 1999] COPE (1999). Committee on professional ethics ethical guidelines for statistical practice. http://www.amstat.org/about/ethicalguidelines.cfm.

[DeVeaux and Velleman, 2008] DeVeaux, R. and Velleman, P. (2008). Math is music: Statistics is literature. *Amstat News*, (375).

[Fecso et al., 1996] Fecso, R. S., Kalsbeek, W. D., Lohr, S. L., Scheaffer, R. L., Scheuren, F. J., and Stasny, E. A. (1996). Teaching survey sampling. *The American Statistician*, 50:328–340.

[Fi and Degner, 2012] Fi, C. D. and Degner, K. M. (2012). Teaching through problem solving. *Mathematics Teacher*, pages 455–458.

[Finzer, 2013] Finzer, W. (2013). The data science education dilemma. *Technology Innovations in Statistical Education*, 7(2).

[Friendly, 2008] Friendly, M. (2008). The Golden Age of statistical graphics. *Statistical Science*, 23:502–535.

[Garfield, 1994] Garfield, J. B. (1994). Beyond testing and grading: Using assessment to improve student learning. *Journal of Statistics Education*, 2(1):2–2.

[Garfield et al., 2011] Garfield, J. B., Zieffler, A., Kaplan, D., Cobb, G. W., Chance, B. L., and Holcomb, J. P. (2011). Rethinking assessment of student learning in statistics courses. *The American Statistician*, 65(1):1–10.

[Gould, 2010] Gould, R. (2010). Statistics and the modern student. *International Statistical Review*, 78(2):297–315.

[Grimshaw, 2015] Grimshaw, S. (2015). A framework for infusing authentic data experiences within statistics courses. *The American Statistician*.

[Grolemund and Wickham, 2014] Grolemund, G. and Wickham, H. (2014). A cognitive interpretation of data analysis. *International Statistical Review*, 82(2):184–204.

[Hardin et al., 2015] Hardin, J., Hoerl, R., Horton, N. J., and Nolan, D. (2015). Data science in statistics curricula: Preparing students to "think with data". *The American Statistician*.

[Harville, 2014] Harville, D. A. (2014). The need for more emphasis on prediction: a 'nondenominational' model-based approach (with discussion). *The American Statistician*, 68(2):71–92.

[Hesterberg, 2015] Hesterberg, T. (2015). What teachers should know about the bootstrap: Resampling in the undergraduate statistics curriculum. *The American Statistician*.

[Higgins, 1999] Higgins, J. J. (1999). Nonmathematical statistics: A new direction for the undergraduate discipline. *The American Statistician*, 53:1–6.

[Hogg, 1999] Hogg, R. V. (1999). Let's use CQI in our statistics programs (with discussion). *The American Statistician*, 53(1):7–28.

[Holdren and Lander, 2012] Holdren, J. P. and Lander, E. (2012). Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics. `https://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final_2-25-12.pdf`.

[Horton, 2013] Horton, N. J. (2013). I hear, I forget. I do, I understand: a modified Moore-method mathematical statistics course. *The American Statistician*, 67(4):219–228.

[Horton, 2015] Horton, N. J. (2015). Challenges and opportunities for statistics and statistical education: Looking back, looking forward. *The American Statistician*, 69(2):138–145.

[Horton et al., 2015] Horton, N. J., Baumer, B., and Wickham, H. (2015). Setting the stage for data science: integration of data management skills in introductory and second courses in statistics. *CHANCE*, 28(2):40–50.

[Horton et al., 2004] Horton, N. J., Brown, E. R., and Qian, L. (2004). Use of R as a toolbox for mathematical statistics exploration. *The American Statistician*, 58(4):343–357.

[Johnstone, 2014] Johnstone, I. (2014). *Where are the majors?*, chapter Past, Present and Future of Statistical Science. Chapman and Hall/CRC.

[Kaplan, 2015] Kaplan, J. (2015). Program assessment for an undergraduate statistics major. *The American Statistician*.

[Khachatryan, 2015] Khachatryan, D. (2015). Incorporating statistical consulting case studies in introductory time series courses. *The American Statistician*.

[Kolenikov, 2015] Kolenikov, S. (2015). Training for the modern survey statistician. *Survey Practice*, 7.

[Lazar et al., 2011] Lazar, N. A., Reeves, J., and Franklin, C. (2011). A capstone course for undergraduate statistics majors. *The American Statistician*, 65(3):183–189.

[Leman, 2015] Leman, S. (2015). Developing a new interdisciplinary computational analytics undergraduate program: A qualitative-quantitative-qualitative approach. *The American Statistician*.

[Madigan and Wasserstein, 2014] Madigan, D. and Wasserstein, R. (2014). Statistics and science: A report of the London workshop on the Future of the Statistical Sciences. `http://www.worldofstatistics.org/wos/pdfs/Statistics&Science-TheLondonWorkshopReport.pdf`.

[Manyika et al., 2011] Manyika, J., Chui, M., Brown, B., Bughin, J., Dobbs, R., Roxburgh, C., and Byers, A. H. (2011). Big data: The next frontier for innovation, competition, and productivity. `http://www.mckinsey.com/insights/business_technology/big_data_the_next_frontier_for_innovation`.

[McNutt, 2014] McNutt, M. (2014). Raising the bar. *Science*, 345:9.

[Moore, 2001] Moore, D. (2001). Undergraduate programs and the future of academic statistics. *The American Statistician*, 55:1–6.

[Moore et al., 1995] Moore, D. S., Cobb, G. W., Garfield, J., and Meeker, W. Q. (1995). Statistics education fin de siècle. *The American Statistician*, 49:250–260.

[Mosteller and Tukey, 1977] Mosteller, F. and Tukey, J. W. (1977). *Data Analysis and Regression: A Second Course*. Addison Wesley.

[Nolan, 2015] Nolan, D. (2015). ESR: An approach to expose undergraduates to authentic data analysis. *The American Statistician*.

[Nolan and Perrett, 2015] Nolan, D. and Perrett, J. (2015). Teaching and learning data visualization: Ideas and assignments. http://arxiv.org/abs/1503.00781.

[Nolan and Speed, 2000] Nolan, D. and Speed, T. (2000). *Stat Labs: Mathematical Statistics Through Applications*. Springer.

[Nolan and Speed, 1999] Nolan, D. and Speed, T. P. (1999). Teaching statistics theory through applications. *The American Statistician*, 53:370–375.

[Nolan and Temple Lang, 2009] Nolan, D. and Temple Lang, D. (2009). *Quality Research in Literacy and Science Education*, chapter Approaches to Broadening the Statistics Curricula, pages 357–381. Springer.

[Nolan and Temple Lang, 2010] Nolan, D. and Temple Lang, D. (2010). Computing in the statistics curriculum. *The American Statistician*, 64(2):97–107.

[Nolan and Temple Lang, 2015] Nolan, D. and Temple Lang, D. (2015). *Data Science in R: A Case Studies Approach to Computational Reasoning and Problem Solving*. CRC Press.

[Pierie, 1986] Pierie, W. R. (1986). Guidelines for bachelor degree curricula in statistics: An interim report. *Amstat News*, 126:23–26.

[Reid et al., 2003] Reid, N., Efron, B., and Morris, C. (2003). Is the math stat course obsolete? https://www.amstat.org/sections/educ/MathStatObsolete.pdf.

[Ridgway, 2015] Ridgway, J. (2015). Implications of the data revolution for statistics education. *International Statistical Review*.

[Ritter et al., 2001] Ritter, M. A., Starbuck, R. R., and Hogg, R. V. (2001). Advice from prospective employers on training BS statisticians. *The American Statistician*, 55:14–18.

[Saxe et al., 2015] Saxe, K., Braddy, L., Bailer, J., Farinelli, R., Holm, T., Mesa, V., Treisman, U., and Turner, P. (2015). A common vision for undergraduate mathematical science programs in 2025. http://www.maa.org/sites/default/files/pdf/ingenious/INGenIOuS-report.pdf.

[Scheaffer and Stasny, 2004] Scheaffer, R. L. and Stasny, E. A. (2004). The state of undergraduate education in statistics: A report from the CBMS 2000. *The American Statistician*, 58:265–271.

[Smucker, 2015] Smucker, B. (2015). Beyond normal: Preparing undergraduates for the work force in a statistical consulting capstone. *The American Statistician*.

[Spiegelhalter, 2014] Spiegelhalter, D. J. (2014). The future lies in uncertainty. *Science*, 345:264–265.

[Starnes, 2015] Starnes, D. (2015). The AP Statistics exam: An insider's guide to its distinctive features. *CHANCE*, 28(3).

[Stodden, 2015] Stodden, V. (2015). Reproducing statistical results. *Annual Review of Statistics and Its Applications*, 2:1–19.

[Sturdivant and Kuiper, 2015] Sturdivant, R. and Kuiper, S. (2015). Using online game-based simulations to strengthen students understanding of practical statistical issues in real-world data analysis. *The American Statistician*.

[Tarpey et al., 2000] Tarpey, T., Acuna, C., Cobb, G., and DeVeaux, R. (2000). Curriculum guidelines for bachelor of arts degrees in statistical science. http://www.amstat.org/education/pdfs/BA-curriculum.pdf.

[Tintle et al., 2015] Tintle, N., Chance, B., Cobb, G., Roy, S., Swanson, T., and VanderStoep, J. (2015). Combating anti-statistical thinking using simulation-based methods throughout the undergraduate curriculum. *The American Statistician*.

[Utts, 2015] Utts, J. (2015). The many facets of statistics education: 175 years of common themes. *The American Statistician*, 69:100–107.

[Wagaman, 2015] Wagaman, A. (2015). Meeting student needs for multivariate data analysis: A case study in teaching a multivariate data analysis course with no pre-requisites. http://arxiv.org/abs/1310.7141.

[Wasserstein, 2015] Wasserstein, R. (2015). Communicating the power and impact of our profession: A heads up for the next executive directors of the ASA. *The American Statistician*, 69:96–99.

[Wickham, 2014] Wickham, H. (2014). Tidy data. *Journal of Statistical Software*, 59(10).

[Wild, 2015] Wild, C. (2015). On locating statistics in the world of finding out.

[Wild and Pfannkuch, 1999] Wild, C. and Pfannkuch, M. (1999). Statistical thinking in empirical enquiry. *International Statistical Review*, 67(3):223–248.

[Wild et al., 2016] Wild, C. J., Pfannkuch, M., Regan, M., and Parsonage, R. (2016). Accessible conceptions of statistical inference: Pulling ourselves up by the bootstraps. *International Statistical Review*.

[Yamamoto, 2013] Yamamoto, K. (2013). Time to play ball. *Science*, 340:1375.

[Zhu et al., 2013] Zhu, Y., Hernandez, L. M., Mueller, P., Dong, Y., and Forman, M. R. (2013). Data acquisition and preprocessing in studies on humans: What is not taught in statistics classes? *The American Statistician*, 67:235–241.

[Zorn et al., 2014] Zorn, P., Bailer, J., Braddy, L., Carpenter, J., Jaco, W., and Turner, P. (2014). The INGenIOuS project: Mathematics, statistics, and preparing the 21st century. http://www.maa.org/sites/default/files/pdf/ingenious/INGenIOuS-report.pdf.