American Statistical Association guidelines for undergraduate programs in statistics

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American Mathematical Society Education Committee

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Executive summary

- The ASA recognizes the importance of undergraduate programs in statistics, and endorsed curricular guidelines in 2000.
- The number of undergraduate statistics majors (while still small in absolute number) has increased more than 140% from 2003 to 2013 (with a 23% increase from 2012 to 2013)
- While many aspects of our recommendations remain the same as the previous guidelines, much has changed and needs to be made more specific and detailed.
- The proposed new guidelines reflect the increased importance of data-related skills in modern practice, with more emphasis on teamwork, communications, and related experiences (e.g., internships, REUs, and capstones)

Executive summary (cont.)

- Undergraduate degrees in the mathematical sciences train students how to solve complex problems in the real world
- We need to adapt our curricula to make them more effective (while continuing to provide theoretical foundations for students heading to graduate school in the mathematical sciences)
- Motivation: other disciplines (primarily computer science and business) have staked their claim to this area. As mathematical scientists, we run the risk of becoming irrelevant if we don't aggressively engage.
- Guidelines and related resources available at http://www.amstat.org/education/curriculumguidelines.cfm

Background: Math Sciences in 2025 report

- “Two major drivers of increased reach: ubiquity of computational simulations … and exponential increases in the amount of data available” (p. 6)
- “Scientific computing pursued in non-unified way” (p. 9)
- “The ability to simulate a phenomenon is often regarded as a test of our ability to understand it” (p. 74)
- “Math sciences curricula need attention. Offerings of typical departments have not kept pace with the rapid changes” (p. 10)
- See also Conrad Wolfram’s TED talk

Background: Math Sciences in 2025 report

- Calls for more mathematical scientists who share the following characteristics (p. 3):
  - “Knowledgeable across a broad range of the discipline”
  - “Communicate well with researchers in other disciplines”
  - “Understand the role of the mathematical sciences in the wider world of applications”
  - “Have experience with computation”

McKinsey report

- McKinsey & Company report stated 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”.
- A large number of those workers will be at the bachelors level.

INGenIOuS report

- “Curricula in the mathematical sciences traditionally aim toward upper level majors’ courses focused on theory”.
- “Shorter shrift is usually given to applications that reflect the complexity of problems typically faced in BIG (Business, Industry, and Government) environments, and to appropriate uses of standard BIG technology tools”.

INGenIOuS report (cont.)

- “The computation that mathematics and statistics majors typically see introduces them to important scientific computing constructs, but it should also help prepare students for big data applications through mathematical and statistical modeling, data analysis, visualization, and high performance computing.”
- “Mathematical sciences departments should modernize programs and incorporate alternative curricular entry points to better capitalize on the interplay of mathematics and statistics with a broad spectrum of career options and better serve students in general.”

Recommendations for new guidelines

- Students need to be able to "think with data."
- They need to have multiple opportunities to analyze data using modern statistical practices, where data is larger, problems are messier, and the answer is not found in a cookbook of formulas.
- Key theoretical concepts need to be integrated with theory, practice, and computation.
- Mathematical techniques play a lesser role, though are still important for people planning doctoral work in theoretical statistics.

Key changes: importance of data science

- Working with data requires extensive computing skills far beyond those described in the previous guidelines.
- To be prepared for data science career expectations, students need facility with professional statistical analysis software, the ability to access and manipulate data in various ways, and the ability to utilize algorithmic problem-solving.
- In addition to more traditional mathematical and statistical skills, students need to be able to be fluent in higher-level languages and be facile with database systems.

Key changes: real data

- 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 real data.
- Instructors need sufficient background and experience with data analysis.

Key changes: more diverse models/approaches

- The expectations for statistical modeling go far beyond a second course in statistics.
- Students need exposure and practice with a variety of predictive and explanatory models in addition to methods for model building and assessment.
- They need to understand issues of design, confounding, and bias.
- They need to be able to apply their knowledge of theoretical foundations to the sound analysis of data.

Key changes: ability to communicate

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

Key skills

- Effective statisticians at any level display an integrated combination of skills that are built upon statistical theory, statistical application, data manipulation, computation, mathematics, and communication.
- Students need scaffolded exposure to develop connections between statistical concepts and theory and their application to statistical practice.
- Programs should provide their students with sufficient background in each of these areas.

Curriculum for statistics majors

- Statistical method and theory
- Data-related topics and computation
- Mathematical foundation
- Statistical practice

Statistical method and theory

- Statistical theory (e.g., distributions of random variables, likelihood theory, point and interval estimation, hypothesis testing, decision theory, Bayesian methods, and resampling)
- Exploratory data analysis approaches as well as graphical data analysis methods
- Design of studies (e.g., random assignment, random selection, data collection, and efficiency) and issues of bias, causality, confounding
- Statistical models (e.g., variety of linear and non-linear parametric, semi-parametric, and non-parametric regression models)

Data-related topics

- Use of one or more professional statistical software environments
- Data manipulation using software in a well-documented and reproducible way
- Basic programming concepts (e.g., breaking a problem down into modular pieces, algorithmic thinking, structured programming, debugging, and efficiency)
- Computationally intensive statistical methods (e.g., iterative methods, optimization, resampling, and simulation/Monte Carlo methods)

Mathematical foundation

- The study of mathematics lays the foundation for statistical theory.
- Undergraduate statistics majors should have a firm understanding of why and when statistical methods work.
- They should be able to communicate in the language of mathematics and explain the interplay between mathematical derivations and statistical applications.

Mathematical foundation (cont.)

- Calculus (e.g., integration and differentiation)
- Linear algebra (e.g., matrix manipulations, linear transformations, projections in Euclidean space, eigenvalues/eigenvectors, and matrix decompositions)
- Probability (e.g., properties of univariate and multivariate random variables, discrete and continuous distributions)
- Emphasis on connections between concepts in these mathematical foundation courses and their applications in statistics (e.g. Markov chains)

Statistical practice

- Effective technical writing, presentation skills, and visualizations
- Teamwork and collaboration
- Ability to interact with and communicate with a variety of clients and collaborators

Next steps

- Guidelines being brought forward for endorsement by the ASA Board of Directors in November
- Will complement the 2013 guidelines for masters programs in statistics
- Related to discussions underway at the NRC Committee on Applied and Theoretical Statistics (CATS)
- Special issue of *The American Statistician* in 2015 on the undergraduate curriculum
- Need for further dissemination, support for transition, new curricular materials and faculty development

White papers

- A variety of white papers are being drafted, including
  - Data science and the undergraduate curriculum
  - Capstones and the undergraduate curriculum
  - Integrating community colleges and undergraduate statistics programs
  - Ethics in the undergraduate curriculum
  - Learning outcomes for undergraduate programs in statistical science
  - Resampling inference and the statistics curriculum
  - Undergraduate internships
  - Next steps for the undergraduate theoretical statistics course
  - Roadmap for smaller schools

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