Curriculum Guidelines for Bachelor of Arts Degrees in Statistical Science

Thaddeus Tarpey  
Wright State University

Carmen Acuna  
Bucknell University

George Cobb  
Mount Holyoke College

Richard De Veaux  
Williams College

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**Key Words:** Liberal arts; Statistics major; Undergraduate Statistics Education Initiative (USEI).

**Abstract**

Curriculum guidelines for a bachelor of arts degree in statistical science are proposed. These guidelines are intended for liberal arts colleges, and other institutions where statistics is taught in departments of mathematics. A flexible curriculum is described consisting of three main parts: mathematics, core statistical topics and a substantive area of study. The curriculum guidelines permit and actively encourage the rethinking of traditional courses and the development of new courses. Guidelines for a minor in statistical science are also proposed. The guidelines are the result of an Undergraduate Statistics Education Initiative workshop held in Alexandria, Virginia in April 2000.

**1. Origins of these Guidelines**

The proposed guidelines described here originated in a workshop, partially supported by the National Science Foundation, which was held in Alexandria, Virginia, on April 28 through 29, 2000. There were 17 representatives from larger universities with separate statistics departments, 18 representatives from smaller post-secondary institutions without statistics departments, and 5 representatives from non-academic organizations that employ statisticians. *Scheaffer (2000)* provides more details and a list of the
participants. A major objective of the workshop was to develop preliminary curriculum guidelines for modern undergraduate programs in statistical science. The first day of the workshop focused on guidelines for undergraduate degrees, with four independent teams working simultaneously. On the second day five new teams were organized. Three worked on curriculum issues of concern to smaller institutions without statistics departments; the remaining two worked on curriculum for students preparing either for graduate work in statistics or a job as an applied statistician. Two writing teams were chosen from the participants in the workshop. One was to focus on curriculum for a Bachelor of Science degree in statistical science, and on minors and concentrations with a similar emphasis. Their report (Bryce, Gould, Notz, and Peck 2001) forms a companion to this one and is recommended as a source of more detail in three areas:

1. some history related to curriculum guidelines in statistics,
2. an account of the discussions at the Alexandria workshop, and, especially,
3. a description of core skills and concepts needed by statistical scientists.

The second writing team, consisting of the authors of this report, was to focus on curriculum guidelines suitable for liberal arts colleges, and other institutions where statistics is taught in departments of mathematics or mathematical sciences. Preliminary drafts of these position papers were presented at the ASA Symposium on the Undergraduate Statistics Education Initiative (USEI) during the 2000 Joint Statistics Meetings in Indianapolis, Indiana.

2. Statistics, the Liberal Arts, and U.S. liberal arts colleges

The guidelines described here are intended for a particular kind of institution, the U.S. four-year liberal arts college. Thus the context for our recommendations involves both the nature of the Liberal Arts and the nature of the liberal arts college. In some other contexts, the phrase “liberal arts” refers to subjects like history and literature that are complementary to the sciences and mathematics. That is not the sense intended here, where the phrase refers to an approach to all learning, not to particular subject areas.

A number of statisticians have written about the natural affinity that links statistics to the Liberal Arts, and we refer interested readers to their work (see, for example, Iversen 1985 and Moore 1998). For the present purpose, we simply summarize briefly one main point: The Liberal Arts are characterized by their attention to the process of constructing knowledge, and to the nature of reasoning and argument. Statistics, regarded as the science of learning from data in the presence of uncertainty, is central to these concerns, and programs of coursework in statistics fall naturally within the liberal arts curriculum.

Moreover, available data suggest the presence of a growing demand for the kind of programs we describe here. Statistics enrollments have been growing steadily in the U.S., at the high school level, at two-year colleges, and at four-year colleges and universities (see, for example, Moore and Cobb 2000, and Moore 2001). However, there are comparatively few departments of statistics, at least in comparison to the number of departments of mathematics. It seems reasonable to expect that for the foreseeable future, much of any growth in undergraduate statistics will have to occur in departments of mathematics (Moore 2001).

In the U.S., liberal arts colleges stand in contrast to universities among institutions that provide a four-year undergraduate degree. Four features of these colleges have contributed to shaping the guidelines we present. First, these colleges give a higher priority to intellectual exploration and attention to the process of learning than to specialized skills and technical preparation for particular jobs. Second, although students typically are required to have a major and a coordinated program of courses outside the major, often called a minor, requirements at individual colleges vary considerably. Third, teaching loads for
faculty at liberal arts colleges tend to be lighter than at other institutions whose main emphasis is on undergraduate education; in return faculty are often expected to maintain at least modest programs of scholarship, and curricular experimentation is typically encouraged or even expected. Liberal arts colleges and other institutions with an emphasis on teaching are often the places where new courses are developed. Indeed curricular experimentation at such places is one of the main ways that new knowledge from research-oriented universities is made accessible to undergraduates. Fourth, at four-year colleges, statistics is almost never housed in a department of that name. Instead, although individual statistics courses may be taught in a number of departments, to the extent that statistics has a home department, that department is mathematics. All four of these features argue for guidelines that offer individual institutions flexibility, and one of the challenges of our working groups has been to find a way to offer that flexibility without sacrificing substance.

Because statistics at four-year colleges is so often housed in a department of mathematics, it is important to emphasize that "although statistics requires mathematics for the development of its underlying theory, statistical reasoning differs from mathematical reasoning and statisticians use many nonmathematical skills" (Bryce, et al. 2001, page 10). "Statistics is concerned with the gathering, organization, and analysis of data, and with inferences with data to the underlying reality. ... The problem of inference from data to reality is very different from the mathematical exploration of the consequences of a model" (Moore 1988, p. 3). Thus the curriculum must be more than a sequence of mathematics courses. Faculty trained in statistics should be involved in developing an undergraduate curriculum in statistical science at any particular institution.

3. Overview of the Proposed Guidelines

The body of our proposal is in three parts. First, in mathematics, we recommend that a B.A. degree in statistical science should include five particular courses in mathematics: three semesters of calculus, and a semester each of linear algebra and probability. Second, in statistics, rather than recommend particular courses, we recommend that the courses leading to a B.A. in statistical science cover a small set of core topics dealing with theory and methods of data production, applied statistical modeling, and inference. Although we consider these topics essential to any major in statistics, we recognize that there are a variety of course structures that present them effectively. Third, we recommend coursework in an area of application as a minor or concentration. In what follows, we give a telegraphic summary of each of the three main recommendations, then provide more detail in a series of notes.

Finally, we suggest that a good way to start building toward a statistical science major is to offer a minor in statistics if that is not already available. An appendix presents guidelines for such a minor.

**Recommendation 1: Mathematics**

The B.A. degree in statistical science should include five mathematics courses: three semesters of calculus, and one each of linear algebra and probability.

The linear algebra course should include basic introductions to matrix algebra, abstract vector spaces, linear transformations, projections in Euclidean space, and eigenvalue/eigenvector decomposition. The probability course need not necessarily approximate the first semester of the standard two-semester sequence in probability and mathematical statistics. Good alternatives include courses with emphasis on stochastic processes or other applied probability models, and simulation-based courses. However, a probability course that serves as prerequisite for mathematical statistics should emphasize connections between probability concepts and their applications in statistics, such as the way various distributions are related to random sampling from a population and data analysis based on random samples.
Experience suggests that for many students, such a course is more meaningful if they have already taken at least one course in applied statistics. Students considering graduate work in statistics should take real analysis, and are encouraged to take other mathematics courses as well. Alternatively, they could consider a minor or the equivalent in mathematics, or even a major in mathematics with a concentration in statistics.

**Recommendation 2: Core Statistics**

*Ordinarily, the B.A. should include at least five courses in statistics, covering data production, applied modeling, and statistical theory.*

Data production should include experimental design, sampling and surveys, and observational studies. Modeling should have an applied emphasis, and should include regression, analysis of variance, and models for categorical data. Statistical theory should include estimation by least squares and maximum likelihood, the logic of hypothesis tests and interval estimates.

The approach to teaching these topics should

- emphasize real (not merely realistic) data and authentic applications, with attention to interpretation of results in their applied context;
- include experience with statistical computing, both for data analysis and for simulation or modern computer intensive methods like the bootstrap, using one or more software packages of the sort used by professional statisticians (programming experience and coursework in computer science are desirable);
- encourage synthesis of theory, methods, and applications, with emphasis on statistical reasoning and problem solving; and
- offer frequent opportunities to develop communication skills through group work, team projects, oral presentations, and writing assignments based on statistical analysis. (Although writing and speaking are a prominent part of the typical liberal arts program we emphasize the particular importance of these skills for statistical work.)

Ordinarily, a B.A. in statistical science should include five or more courses in statistics, although the balance between required core courses and electives will depend on the institution. There are many different courses and course sequences that cover the core topics mentioned above. An example of one recommended sequence follows. For an alternative, see (Cobb 1999).

- Introduction to Statistics
- Applied regression
- Statistical theory and methods (2 semesters)
- Capstone course

An introductory course (see Garfield, Hogg, Schau, and Whittinghill 2002) is often based loosely on the Advanced Placement syllabus, although we also encourage other structures that offer multiple entries into the statistical science major. In recommending an introductory statistics we note that there are successful majors that do not require the usual sort of introductory course. An applied regression course is recommended as an excellent vehicle for teaching core material, and such a course is described in detail in the associated position paper "An Example of a Second Course in Applied Statistics: Regression Analysis" by Halvorsen, McKenzie and Sullivan (2002). 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.

Finally, by a capstone course we mean a senior-level course involving one or more data-production-and-analysis projects intended to lead students to synthesize and apply what they have learned in their other statistics courses. A capstone course also provides an opportunity to integrate statistical knowledge with other substantive areas (see Recommendation 3 below.) Throughout the statistics curriculum and particularly in the capstone course, students should become familiar with the ASA ethical guidelines (ww2.amstat.org/profession/ethicalstatistics.html). Of special importance are issues of confidentiality and impartiality when dealing with data collection and the reporting of results. In smaller departments where it may be difficult to offer a capstone course each year, a senior thesis project could be required instead. Hands on experience can also be gained through internships and consulting.

There are many statistics electives that might be included in a statistical science major. In some instances one of the topics listed below might be the focus of an entire undergraduate course. In other instances topics from this list might be interwoven with topics from the statistics core.

- Applied multivariate analysis
- Time series
- Generalized linear models
- Statistical genetics
- Categorical data analysis
- Statistical process control
- Mathematical statistics
- Data Mining
- Computer Intensive Methods (bootstrap, permutation methods, et cetera)

This list is not meant to exclude other possibilities. In particular, new topics will become appropriate as statistical methodology evolves. Depending on content, upper division courses like econometrics, which have a statistics emphasis but are taught outside a department of mathematical sciences, might well be acceptable as statistics electives counting toward the major.

**Recommendation 3: Area of application**

*Statistics, being a methodological discipline, must be applied in some other area.*

Students whose interest is primarily in applied statistics are encouraged to plan a coordinated program of three or four courses in an area of application such as economics, psychology, or biology. Here, as elsewhere, details are left to individual institutions.

**4. Summary**

Table 1 presents a bare-bones summary of the recommendations for a major in statistical science as part of a B.A. degree.

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**Table 1.** Guidelines for a Bachelor of Arts degree in Statistical Science.
Appendix. Statistics Minor or Concentration

By a concentration, track, or emphasis in statistics we mean a collection of courses within a major (such as biology, business, or mathematics) that demonstrates a special focus in the field of statistics. A minor in statistics is designed to encourage students majoring in a subject other than statistics to gain a deeper understanding of statistics than would come from just one or two courses. The number of courses required for a minor may vary, typically from five to seven, depending on individual institutions. Since students will be undertaking the coursework for this minor in addition to requirements for a major in another area, the recommended requirements focus on courses in statistics, without including other courses in mathematics or computer science. Although some of the possible statistics electives might have mathematical prerequisites, a student in the social sciences should be able to complete a statistics minor without taking a calculus course. Note that courses from several departments might be allowed to count toward a statistics minor, although care must be taken to avoid excessive overlap and ensure sufficient statistical content.

Curriculum for a Minor/Concentration

Core Statistics Topics (2 courses). A sequence of two courses (for example, an introductory statistics course and an applied regression course) that cover the core topics (data production, inference, and applied modeling) as described in Recommendation 2. Courses in a student's major discipline that overlap substantially with either course in the core sequence may be substituted provided they are comparable in both content and depth.

Electives (3 to 5 courses - depending on individual institutions). Possible electives include any courses that would qualify for the major in statistical science. In particular, some electives might be courses like econometrics that are taught in other departments and have a substantial statistical component distinct from the introductory material of the core sequence. Although a probability course would not ordinarily be part of a minor with an applied emphasis, it might be appropriate for some students.

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Thaddeus Tarpey
Department of Mathematics and Statistics
Wright State University
Dayton, OH 45435
USA
ttarpey@mail.wright.edu

Carmen Acuna,
Department of Mathematics
Bucknell University
Lewisburg, PA 17837
USA
cacuna@bucknell.edu

George Cobb
Department of Mathematics, Statistics and Computer Science
Mount Holyoke College
South Hadley, MA 01075-1411
USA
gcobb@MtHolyoke.edu

Richard De Veaux
Department of Mathematics and Statistics
Williams College
Williamstown, MA 01267
USA
deveaux@williams.edu