Undergraduate Programs and the Future of Academic Statistics

David S. Moore

1. INTRODUCTION

The American Statistical Association is considering whether to issue recommendations concerning undergraduate programs in statistics. The primary intent of such programs is not to prepare students for graduate study in statistics, but to equip them for employment with a bachelor's degree or for further study in a wide variety of areas. The proposal that ASA offer its blessings to undergraduate programs is not universally accepted, because statisticians are generally expected to have graduate training. This paper does not offer opinions on the content of undergraduate programs, but rather presents some factual background material that we should consider in designing them, with some suggestions based on this background. "The future for academic statistics" may seem an odd theme. One of my theses, on the basis of which I advocate ASA action regarding undergraduate study, is that while the discipline of statistics is healthy, its place in academe is not. Our future there depends strongly on achieving a more prominent place in undergraduate education beyond the first methods course. This in turn depends on greater cooperation between statistics and other disciplines, especially mathematics.

The paper has four main sections. Section 2 stresses that undergraduate statistics programs *in mathematics departments* (or perhaps cross-departmental programs involving other disciplines) must be our focus. It would repeat false starts from the past to think primarily of statistics departments, or even of large research universities more generally. The next section presents some market research—data on trends that ought to influence our thinking about statistics for undergraduates. In Section 4, I offer some cautionary findings from research in mathematics education. The unifying theme of these three sections is the need for realism in discussing programs for undergraduates. It is easy to be unrealistic. The traditional approach—starting by formulating a list of topics that everyone appying statistics should know—is almost certain to generate recommendations that most institutions cannot follow and that most students cannot master. The concluding section offers some opinions and advice on the basis of the more factual content in the first three sections.

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2. MATHEMATICS AND STATISTICS

The Bureau of Labor Statistics (2000) says that "In 1998, approximately 110 universities offered a masters degree program in statistics, and about 60 offered a doctoral degree program." Here, in contrast, is the universe of degree-granting institutions in the United States (NCES 1999b):

Degree-Granting Institutions, 1997

Type	Count	Students	Undergraduates
Four-year public	629	5,835,433	4,646,793
Four-year private	1695	3,061,332	2,198,225
Total	**2324**		**6,845,018**
Two-year public	1099	5,360,686	
Two-year private	651	244,883	
Total	4074	14,502,334	12,450,587

The two-year college totals are impressive, but to begin discussion of undergraduate programs in statistics we might focus on the four-year colleges: more than 2300 institutions with (by now) more than 7 million undergraduate students. Few of these institutions have statistics departments. If we wish to encourage study of statistics by undergraduates, we shall have to gain the cooperation of other disciplines. In the case of undergraduate majors, the mathematics department is the natural home of statistics. Minors or concentrations in statistics may target students in other disciplines, but even these will often require the cooperation of the mathematics department. Of course, the mathematics departments at many institutions lack the resources to offer more than a few statistics courses. Realistic plans will keep this in mind.

Moore and Cobb (2000), in a forum read by mathematicians, discuss in detail the need for cooperation between mathematics and academic statistics. Here are some themes from that discussion:

Statistics is culturally healthy, but academic statistics is endangered. Some indicators of the cultural health of statistics relative to mathematics are:

- Higher nonacademic employment. About half of statistics Ph.D.s take nonacademic jobs. This is misleadingly low because statistics, unlike mathematics, has a highly-valued professional Master's degree.

- Higher proportion of women.

- Strong computational, applied, interdisciplinary emphasis, with ties to many fields.

- Revitalized by technology.

- Rapid enrollment growth in elementary courses. Data from the most recent CBMS census appear in Section 3.

Most statisticians are familiar with these happy facts. Yet the indicators of organizational weakness in academic statistics are equally well known:

- Small departments, weak players when resources are contested, fragmented teaching.
- "Statistics without statisticians." Hahn and Hoerl (1998) use this phrase to describe the state of statistics in industry. It is equally true in academe that everyone uses statistics but statisticians are few.
- Slow or no growth outside first courses. The same CBMS census that shows rapid growth in elementary statistics shows stagnation above that level. Few students take more than one statistics course.
- Does the field have a core? This is the reverse side of the medal awarded for interdisciplinary activity: what do "statisticians" engaged in market research and molecular biology have to say to each other?
- Will statistics be swallowed by broader information technology? This is the reverse side of the medal awarded for responding to new technology.

Attracting students to undergraduate programs in statistics would address many of these weaknesses. We might hope—for the first time in many institutions—to make statistics visible as a discipline and viable when departments make hiring plans and campus administrations allocate resources.

Mathematics is organizationally strong, but insular. Why should mathematics departments devote more attention to statistics? Mathematics does not share the vulnerabilities of statistics—there will always be a mathematics department, in universities, four-year colleges, and even many two-year colleges. There are even now not many statistics departments and that number may shrink. The besetting weakness of academic mathematics (and that is almost the only kind of mathematics) is insularity, failure to reach out to other disciplines and to participate in the general advance of science. Many mathematicians recognize this weakness, though efforts to overcome it encounter strong resistance. Here is what the American Mathematical Society found when it interviewed deans at research universities (Ewing 1999):

> The prevalent theme in every discussion was the insularity of mathematics. Mathematicians do not interact with other departments or with faculty outside mathematics, many deans claimed, and they view this as a problem both for research and for teaching. In many cases, deans contrasted mathematics with statistics, which they pointed out had connections everywhere.

A distinguished international group of mathematicians invited to assess the state of U.S. mathematics said much the same thing (NSF 1998): "Communication between mathematical scientists and other scientists is poor the world over."

The two academic disciplines need each other. Statistics, in most academic institutions, needs the organizational shelter of the mathematics department. The mathematics department needs to reach out to its campus, and statisticians can help. Here are some indicators that synergy is possible. Moore and Cobb (2000) again give a full discussion.

- Mathematics and statistics are natural allies in the argument between thought and automation. Both fields think they bring things that cannot be automated.
- Statistics undergraduate programs need mathematics courses. Statistics graduate programs need undergraduate mathematics majors.
- Statistics can serve as a model for teaching that builds on applications and applies technology, and as a model for outreach via consulting services, campus connections, and joint appointments.

It should be clear that in considering undergraduate programs, research universities with separate statistics and/or biostatistics departments are not a universal model for either mathematics or statistics. The relatively few Ph.D.-granting statistics departments are obviously not a model for statistics undergraduate programs in other types of institutions. Neither are mathematics departments that can ignore statistics because it lives elsewhere. In almost all other institutions, academic statisticians must seek shelter in the mathematics department. The mathematics department would be wise to welcome them. It is thus of first importance that recommendations for undergraduate programs in statistics be realistic in a wide variety of institutions and acceptable to many mathematicians.

3. SOME TRENDS TO WATCH

We cannot intelligently design new products without a sense of the market. Here is some market research, data on trends that will affect any recommendations we make.

The democratization of education. We don't need OECD (2000) to tell us that "Tertiary education is now replacing secondary education as the focal point of access to rewarding careers." Here is an excerpt from Table C3.4 of the OECD report (data for Canada are unfortunately missing):

	University entry rate	% Change 1990–1997
Australia	53%	+31%
New Zealand	68%	+43%
United Kingdom	48%	+101%
United States	44%	+8%

The "percent change" in this table is the percent attributable to changes in enrollment rates. This removes the effect of changes in the size of the age cohort. The change since 1990 in the United States is low because the U.S. led the way in sending a high percent of secondary graduates to college. The U.S. entry rate is misleadingly low because OECD reports only direct entries to four-year institutions. Alone among these nations, the United States has an extensive network of two-year colleges which are often the first step toward university. Figure 1 (based on data from NCES 1999) shows the percent of U.S. secondary graduates who are in post-secondary education the following October. For 1998, this is 65.6%.

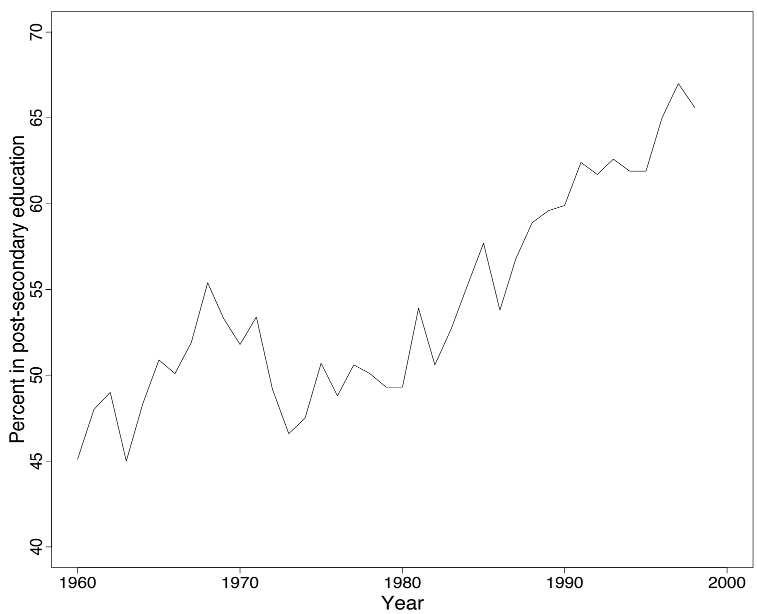

Figure 1. Percent of secondary school graduates entering higher education.

It should be clear that college students are no longer an elite. Programs and courses aimed at students who are "like us, only younger" are not realistic when two-thirds of all secondary school graduates sit before us. It is no doubt also true that democratization creates demand for directly employable subjects at the expense of the older "arts and sciences.". Statistics is one such subject. At all but a few elite institutions, the argument that we should educate students rather than train them (an argument based on a dubious distinction) is now an anachronism. Democratization is one explanation for …

Increasing statistics enrollments. Here are data from the every-five-years CBMS census of mathematical sciences departments (Loftsgaarden, Rung, and Watkins 1997):

Elementary Statistics (thousands)

	Math depts	Stat depts	2-year colleges	Total
1990	87	30	54	171
1995	115	49	72	236

More striking is the fact that though we hear that society and employment are becoming ever more quantitative, statistics is almost the *only* thing taught in mathematics departments that is growing:

Mathematics (thousands)

	1985	1990	1995	1990–1995	1985–1995
Calculus	637	647	539	−17%	−15%
Advanced	138	119	96	−19%	−30%

These data are one reason why it is in the interest of mathematics departments to welcome statisticians and statistics programs.

Better high-school preparation. Yes, it's true: more students are now prepared to study statistics in college, at least on paper. Figure 2, based on data from NCES (2000) shows that an increasing fraction of U.S. secondary school graduates have taken chemistry or physics and advanced mathematics (defined as at least precalculus).

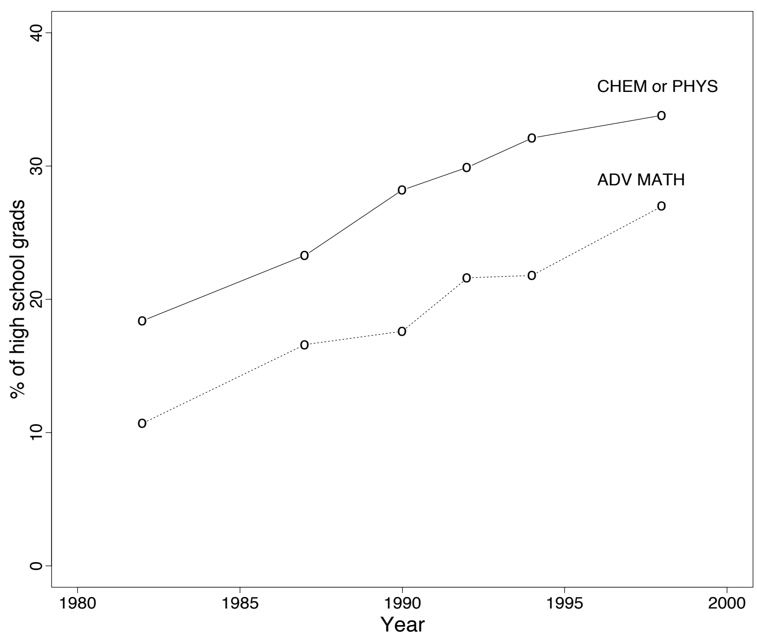

Figure 2. Percent of high school graduates taking advanced subjects.

Presumably students who took courses in advanced mathematics in high school are the primary recruiting grounds for undergraduate programs in statistics and other quantitative disciplines. For the first time, significant numbers of students are seeing data-oriented statistics in high school:

Advanced Placement Statistics	
1997	7,500 exams
1998	15,486 exams
1999	25,240 exams
2000	35,000 exams

The recruiting pool: leaders and laggards. Where are the growing numbers of quantitatively-prepared students going when they enter college? Figures 3 and 4 show the numbers of bachelor's degrees conferred by U.S. colleges and universities in selected fields of study. (The data are from Table 255 of NCES 2000.) Figure 3 displays "leaders," fields which award large numbers of degrees and have in most cases shown substantial recent growth. I have chosen business, biology and health sciences, and psychology because practitioners in these areas make substantial use of statistical methods.

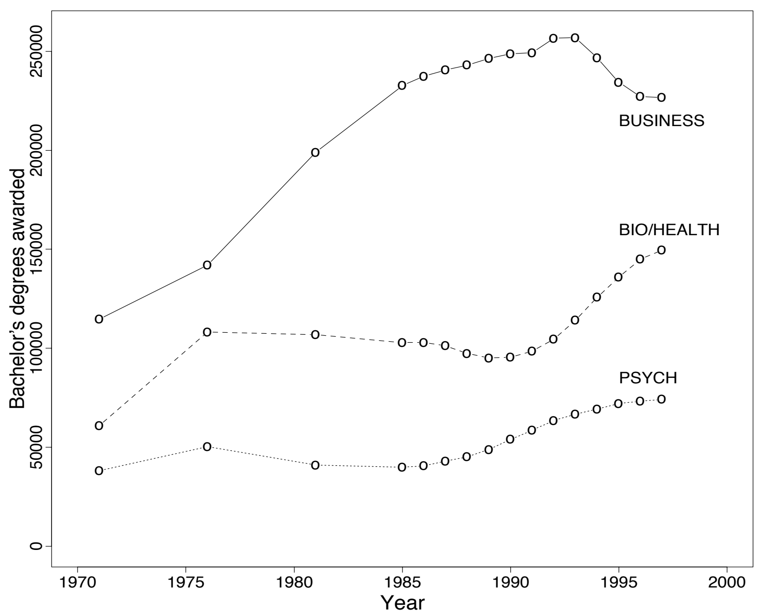

Figure 3. Leaders: disciplines awarding large numbers of degrees.

Figure 4 displays "laggards," fields in which fewer degrees are awarded and which have been stable or declining in recent years. The scale is the same as that of Figure 3 to allow easy comparison. These are "technical" fields that require substantial mathematics. Engineering, physical sciences, and especially computer science and information technology are often thought of as competing with mathematics for quantitatively prepared undergraduates. Note that even computer science and information technology awarded 41% fewer degrees in 1996–97 than at their peak in 1985–86. (In all disciplines, almost 19% more bachelor's degrees were awared in 1996–97 than in

1986–86.) We sometimes hear that students are shunning mathematics in favor of computer science. In fact, students are avoiding all of these laggard disciplines.

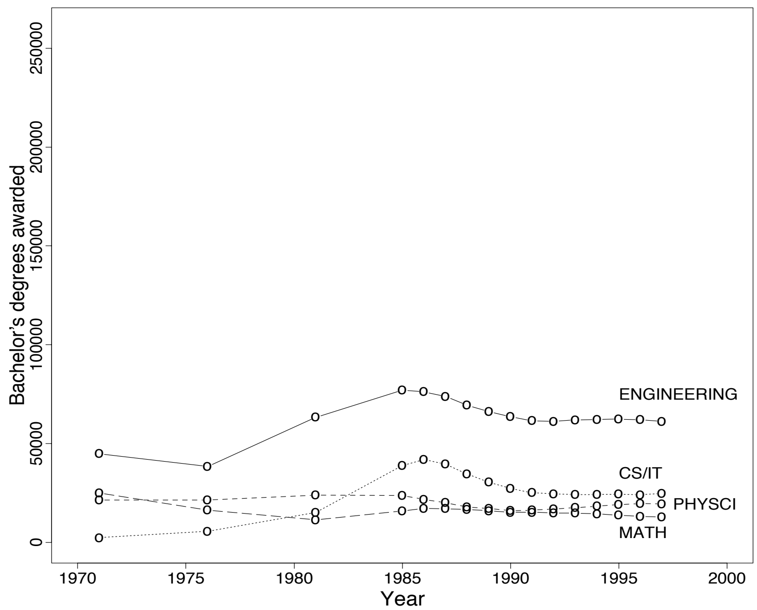

Figure 3. Laggards: disciplines failing to attract large numbers of students.

One distinction between leaders and laggards is that the leaders use more statistics (but less mathematics). Another is that statistics programs have traditionally recruited mathematics majors and felt they were competing for students with the other laggard disciplines. The bit of market research reported in Figures 3 and 4 suggests that programs appealing to students in the leading disciplines are more promising. These will more often be minors or concentrations within a program outside the mathematical sciences rather than full undergraduate majors.

Nonstop education and training. Although not directly related to the question of undergraduate programs, the rise of continuing education is too important to ignore. Here, again from OECD (2000) are the percents of employed adults who had engaged in job-related continuing education within the past year, as of 1995:

	All employed adults	University educated
Australia	41%	60%
Canada	38%	56&
New Zealand	51%	69%
United Kingdom	56%	79%
United States	47%	70%

People with a university education are most aware that they must continue to learn or fall behind. This is a large market, and one in which the power of their brands should enable colleges and universities to compete effectively. Some new courses may serve both on-campus undergraduates and the continuing education market, strengthening the case for devoting more resources to statistics courses.

Technology in the saddle. It is of course technology that is driving all the trends we are watching. Technology has changed statistics, so that our field has moved somewhat away from mathematics back toward its roots in data analysis and scientific inference. Technology is driving demand for quantitative skills, including statistical skills. Technology is now the most important tool for all the sciences and applied sciences, displacing both mathematics and statistics from traditional roles. Mathematics advances largely from within, and will survive. Statistics is inherently methodological, and so is under threat.

4. WISDOM FROM MATH EDUCATION RESEARCH?

I put a question mark in the head not because I doubt the value of research in math education, but because of a skeptical principle: we are always just at the point when education research will at last help ordinary teachers. My primary source for this section is Niss (1999), a survey and interpretation by Mogens Niss of Denmark delivered at the International Congress of Mathematicians in 1998, supplemented by conversations with Niss. See also Niss (2000). He does think that the accumulated work in mathematics education can help teachers. Here are some findings from that work that I believe.

Limited success. Many students never acquire conceptual understanding or flexible skills that they can apply in settings new to them. Note that this is a *finding* from systematic investigation, not just our anecdotal experience as teachers. That we have a history of failure is distressing but true. That history is part of the background for realistic thinking about undergraduate statistics.

Drill only teaches drilling. Procedures and understanding are separate domains. Drill on procedures is not for this reason unimportant, but we should not be under the illusion that doing a procedure many times helps students understand it. The fastest way to cover ground in teaching statistics is to emphasize a list of procedures, with or without software. This approach almost guarantees that many students will be unable to apply the procedures even in settings that seem to us essentially the same as those used in teaching.

The math model doesn't work. Mathematically-trained teachers often imagine that they can gain efficiency by presenting general principles or structures first, followed by concrete "special cases." This doesn't work. Few people learn from basic principles down to special cases. Seeking efficiency in this way was the primary failing of the New Math movement of a generation ago. Niss goes so far as to say that the failure of New Math redirected research in mathematics education away from how to present material toward attempts to discover how students learn. "Theory first" in basic statistics is destined to fail—students have no idea what this is the theory of.

Reifying processes is particularly hard. This is a more concrete finding that is interesting enough to mention: turning a process into an object is always a difficult mental leap. Students who can easily evaluate a function for any argument have great difficulty thinking of the function as an entity to be studied in its own right. Students who can differentiate fluidly have difficulty conceiving "the derivative" of a function as a separate entity. An obvious statistical instance of this generic barrier is the sampling distribution. Even when approached concretely and with minimal formal mathematics, elementary statistics involves difficult ideas.

Naive constructivism. This is the paradigm for how students learn that has emerged from the past generation of study in mathematics education. It is now familiar and seems almost obviously true: students learn through their own activities, not by passive information transfer. Good teachers structure and encourage their learning. The catch is that until students learn how to learn—that is, learn how to create their own interaction with lecture and text—applying the constructivist principle considerably slows our progress through the appointed syllabus. We assume that graduate students have learned how to learn. We should be cautious in making that assumption about many undergraduates.

I have called the basic principle "naive constructivism" to distinguish it from various supposedly more sophisticated versions. These often appear to regard knowledge as socially or even individually constructed in a way that disregards or denies any truth "out there." Various elaborated forms of constructivism are popular among education researchers, and have given the entire paradigm a bad name among scientists. Let's stay naive.

It appears that the tentative conclusions of research in mathematics education are largely pessimistic. We have a history of failure; such popular approaches as drill-drill-drill and theory-first are known to be ineffective; the more we look at how students deal with such central ideas as sampling distributions, the harder these ideas seem; we must slow down to give students a chance to interact with our teaching and build their own understanding. All this is also important background for thinking about undergraduate programs.

5. UNDERGRADUATE PROGRAMS IN STATISTICS

The information presented to this point leads, I think, to some conclusions. First, **diminished expectations:** we can't teach a wide audience what we might like to "cover." The realities exposed by mathematics education research, the desire to bring statistics programs to a large number of institutions, and the nature of the disciplines that currently attract students all urge caution in drawing up the inevitable list of essential topics. Niss warns against the "dreaded disease *syllabitis*" that assesses a course or program by the length of the list of topics.

A second conclusion follows: **no undergraduate program is intended to train professional statisticians**. For better or worse, statisticians are defined as having at least a Master's degree or equivalent experience. Holders of a bachelor's degree may eventually reach this status via on the job training and practical experience, but their degree does not equip them for professional practice. We have, I think, found it hard to escape assessing undergraduate programs against professional standards. Once liberated from such narrowmindedness, we can design programs that are accessible to many undergraduates and that offer flexible quantitative skills suitable for a variety of careers.

Statistics in practice has moved away from mathematics. So have the interests of students. These facts present a dilemma. Mathematics is important in statistics, and more is better. "You can never be too rich or too thin or know too much mathematics." Perhaps more important, academic statisticians in most institutions have nowhere to hide outside the mathematics department. A proposal for a statistics major must therefore be acceptable to mathematicians. Mathematicians have been slow to amend traditional programs in mathematics to fit the current undergraduate market, and may not accept realistic majors in statistics.

One conclusion that follows from our mathematics dilemma is that **parts may be more realistic than wholes**. That is, most institutions should start by offering minors or concentrations in statistics, especially for the disciplines that appear as "leaders" in Figure 3. A mathematics department that adds a course in applied regression and negotiates with the business, biology, and psychology departments may find a booming market for a statistics minor aimed at the more quantitative students in these fields. Such a minor might require some additional mathematics as well as statistics. Statistics tracks within the mathematics major are also attractive. These need not require a large number of statistics courses—we are not training statisticians, and a mix of computing, mathematics, and statistics may be acceptable to the math department as well as attractive to students. Yes, it enters my mind that some students, both in mathematics and in other disciplines, will be drawn to statistics and will seek graduate education in our field. Even if we aim to attract graduate students, our most effective strategy is to propose realistic programs for wide audiences rather than idealized grad-school-prep programs.

Commenting on the address on which this paper is based, Joe Ward noted that my final points were **sell, sell, and sell**. Can we sell our ideas to the institutional majority? Can we sell realistic proposals to mathematics departments? Can we sell our graduates to employers? The specific guidelines that ASA may eventually adopt and publicize must be sales material. That is not their only purpose, but it is important to their success. We will not build Utopia, and there is no sense in being utopian.

Statisticians know that our greatest challenge is not to sell our graduates, but to sell our discipline. I can't resist concluding with a sample of how the educated public thinks of statistics. The *Financial Times* is one of the world's more serious newspapers, known for its informed and sophisticated columnists. Here is one of those columnists (Kellaway 2000) on a statistical topic:

> So far, I have failed to tell you what Six Sigma actually is. The reason is that I haven't the foggiest. Six Sigma is something to do with total quality management – only the book says it's much, much better. I think sigma is a measure of statistics, and I gather low sigma is bad and high sigma is good. Whatever. It's big: your profit margins will go up by 20 per cent a year for each sigma shift.

Broader exposure to statistics beyond a first course by much larger numbers of undergraduate students gives us at least the opportunity to sell our discipline more effectively.

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