Statistics Education *Fin de Siècle*

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Abstract

Higher education faces an environment of financial constraints, changing customer demands, and loss of public confidence. Technological advances may at last bring widespread change to college teaching. The movement for education reform also urges widespread change. What will be the state of statistics teaching at the university level at the end of the century? This article attempts to imagine plausible futures as stimuli to discussion. It takes the form of provocations by the first author with responses from the others on three themes: the impact of technology, the reform of teaching, and challenges to the internal culture of higher education.

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1. INTRODUCTION

Like the last fin de siècle, the end of the twentieth century features rapid change and the dissolution of old ways. The USSR is gone, and IBM is tottering. Research universities, which have dominated the U.S. academic scene since World War II, are retrenching in the face of resource restrictions and public criticism. Social changes, both in the backgrounds of entering students and in the skills valued in the labor market, challenge education systems at all levels. Technology promises (or threatens) to change everything, but education changes only slowly. Strong education reform movements demand radical change as well, and again the response seems slow.

University faculty are, like most privileged elites, conservative. We only slowly adopted the style of the entrepreneurial fund-seeking researcher that has been encouraged (even enforced) at major universities in recent decades, and now we are reluctant to abandon that style. Our lecturing has been largely unaffected by waves of technology and of educational reform. The central theme of the "provocations" below is this: Higher education possesses a strong internal culture that has changed little in the past forty years, but is now under such intense pressure that rapid and uncomfortable change is likely. In the spirit of end-of-the-century reflection, it may be useful to put aside our convictions about the special nature of higher education and look at ourselves as a high-cost, labor-intensive service industry that, like so many other industries, is about to be restructured.

This paper is more an exercise in imagining the future than in sober prediction. We suggest that rapid and no doubt unpredictable changes in higher education will soon occur. We offer some guesses about the impact of our imagined futures on statistical education, guesses that may well be wrong but that are intended to provoke thought.

2. TECHNOLOGY TRIUMPHANT?

2.1 Provocation by David Moore

I once spent an undergraduate summer in Princeton computing double star orbits with a desk calculator for a distinguished astronomer. Each lengthy calculation produced a point on a graph. Theory said the points should form a parabola, but observational error produced lots of scatter. After weeks of calculating I sharpened a pencil and drew a parabola through the points freehand. The distinguished astronomer was pleased. He said he could tell I was a mathematics major because my parabola looked like a parabola. When I arrived at Purdue a few years later, I repeated this story to an older colleague. "Well," said he, "I once visited some engineers who also had a theory that said data points should form a parabola. They were fitting a parabola by putting the graph paper on the wall and hanging a chain through it."

The point of these anecdotes from the dark ages is that things have changed. The computing revolution has made data-analytic procedures much more sophisticated than fitting a parabola easily available to engineers and scientists everywhere. General journals such as *Science* carry advertisements for software packages that promise to carry out complex statistical analyses as well as to prepare elaborate presentation graphics in several colors. Astronomers no longer hire undergraduates to calculate double star orbits and fit parabolas by hand. Expectations rise with prosperity, of course. Present-day astronomers are more likely to search large data bases of the Doppler redshifts of galaxies for voids and filaments and to ask if these features are "significant" in the sense of requiring systematic explanation (Feigelson and Babu 1992).

Statisticians have not been slow to take advantage of fast and cheap computing. Old methods such as regression now come equipped with a bewildering variety of diagnostic tools. More general classes of models (generalized linear models, generalized additive models) describe a wider variety of phenomena. Bootstrapping and subsampling produce error estimates and confidence intervals in previously intractable settings. Each year seems to bring new ways of smoothing data by fitting general classes of functions. The nature of both statistical research and statistical practice have changed dramatically under the impact of technology.

Our teaching has certainly changed as well—but what strikes me is how little it has changed. We ask students to use software, we do a bit of diagnostics when we teach regression, we add recent topics to more advanced courses. Yet our fundamental modes of interacting with students are as they have always been. The computing revolution has changed neither the nature of teaching nor our productivity as teachers.

> **Question 1:** Why hasn't technology changed the teaching of statistics more? Why hasn't it improved the efficiency and productivity of teaching?

I suggest that the limited impact of technology on teaching is rooted in cultural resistance to change in colleges and universities, strikingly similar to the change-resistant culture that is being swept away in many other enterprises. Consider the parallels:

- Our costs have risen much faster than incomes or inflation. Teaching remains labor-intensive craft work. Our customers are showing price resistance.

- We see no need to change. I have taken part in several discussions on the application of quality management ideas to universities. The visceral reaction of faculty to sensible ideas is striking. Professors, those most individualistic beings, argue that effective education is inherently personal and hence labor-intensive.

We *like* being craft workers. We stiffen at the very mention of "productivity." We resist "management" of our activities. Increased use of technology seems to threaten more uniformity and less individualism in teaching practices. "Variation is the enemy of quality" is not an aphorism that professors apply to teaching.

- We have an outdated organizational structure. Data analysis in practice is assimilated into the everyday work of astronomers and engineers and business analysts, many of whom, aided by technology, do very sophisticated analyses indeed. Similar assimilation of method and substance, aided by technology and team teaching, would improve both our customer satisfaction and our productivity. Yet we cling to disciplinary and departmental boundaries that are more relevant to research specialization than to teaching.

- There is little internal incentive to change. We are ranked, as individuals, departments, and institutions, by our peers, specialty by specialty. Neither societal needs nor priority for teaching can squeeze through the narrow filter of our specialization. It is not surprising that we are very good indeed at specialized disciplinary research and less good at other tasks.

In this cultural setting, we immediately apply new technology to our research. Teaching? Our costs are high, technology is expensive, the staff likes things as they are. We have no long term plan to gain efficiency, so investment is hard to justify. In other industries, this is a description of a firm that will soon go out of business. Many teachers do, of course, take the time to use technology well despite the lack of incentives. But as long as reform of teaching depends on the activity of individual faculty in individual courses, little will be accomplished. Major improvements in quality or efficiency require systemic change.

Traditional ways of organizing and subdividing work are under attack in many service industries and in the service operations of manufacturing firms. Traumatic reorganization and reduction of white-collar staff has been a feature of the recent recession that appears permanent and may even be bringing about, at long last, increases in service productivity as fewer people in fewer organizational cubbyholes use more technology more effectively. Higher education cannot escape this trend. We statisticians teach a subject whose practice is technology-based, cuts across many disciplines, and is carried out by teams rather than by individuals. We ought to lead in incorporating these trends into our teaching as well.

Technology does not stand still. While we think about using existing technology, new revolutions are on the horizon. The last computer revolution replaced IBM by Microsoft as the dominant firm in the industry, drove Wang into Chapter 11, and

much more. It is hard to miss the buzzwords of the next revolution: digital convergence ("bits are bits") and interactive multimedia. The media, communications, and computer businesses are coming together. Apple, IBM and Scientific Atlanta square off against Intel, Microsoft and General Instrument in a battle to set the standards and make the box that will bring 500 channels of interactive digital television/computing to homes. Others, wagering that wires will be bypassed by wireless computing, seek alliances with cellular phone companies. Video game makers team with data base designers, and everyone seeks to buy up electronic rights to libraries of books or video. The *New York Times*, commenting on the planned merger of Bell Atlantic and Tele-Communications Inc., loses its customary reserve: "a majestic vision of how modern communications would transform the American home," "a vast panoply of programming and information offerings that are available at the flick of a wrist whenever a consumer wants to see them." (Fabrikant 1993)

The entertainment potential of multimedia technology is so great that it is certain to become (in what form is *not* yet certain) both a major industry and a major part of everyday life. A longstanding theme of educational technology is that it is always the *next* generation that will at last bring about basic changes in education. The next generation now seems unusually promising: integrated multimedia systems that present students with text, sound, full-motion video and friendly calculating and graphics capacity, packaged by clever instructional designers so that a student actively interacts with the system using keyboard, mouse and voice. The "teacher" is patient, always available, and adjusts to individual rates of progress.

> **Question 2:** What will be the effects on education of yet more technology? Will interactive multimedia systems finally change the nature of at least beginning instruction in statistics?

Absent other changes, I suspect not. But other changes will come. Colleges and universities rely on their "brand names" to attract students, arguing in part that brand recognition will help their graduates in the marketplace. In other competitive arenas, brand is beginning to matter less than value. Even Marlboro must cut its prices to compete with generic brands. Let us also suppose that a generic college decides to use some of those 500 cable channels to offer access to an interactive multimedia instructional system at all hours and at prices a fraction of those charged by residential colleges. Could we maintain our collective monopoly? How many luxury brands can the market support once true generics offer genuine value?

The *Economist*, to celebrate its 150th year, commissioned a set of essays on the future. Diane Ravitch entitled her essay on education "When School Comes to You." Anthony Smith, former director of the British Film Institute, called his piece on entertainment "The Electronic Circus." And John Kay of the London Business School

listed among the leading companies of the year 2093 the Education Corporation of America (ECA), which operates a "chain of universities" and "schools in 45 of the 53 states" (Kay 1993). Will we change enough to face competition from ECA?

2.2 Primary response by William Meeker

Organizations attempt major structural changes when faced with threats to their continued existence. Some survive through reorganization (often reducing white-collar staff) or by improving quality and productivity within an existing organizational framework. Others disappear. Despite tight budgets and occasional painful downsizing, few universities have yet faced direct threats to their existence. David suggests that emerging technology may allow a competitor to offer a higher education product that provides better value due to much lower cost. Colleges and universities would then be in exactly the position that has driven many firms to change or die.

It is true that many universities are implementing Total Quality Management (TQM) ideas. For the reasons David outlines, however, the implementation has been largely in the nonacademic parts of universities. Except in isolated cases (e.g., Bateman and Roberts 1993), TQM has had little impact on teaching or research. Faced with real competition, colleges and universities may attempt some combination of these responses:

- Justify a high price by improving the quality of what students receive.
- Reduce costs by delivering education to more students with fewer resources.

I will suggest how technology can contribute to both goals. As in the private sector, however, we may find that technology applied without rationalizing our organization and adopting a consistent quality philosophy is an inadequate response to competition and customer demands. In that case, as Section 4 of this paper suggests, we will be in real trouble.

Technology has already improved the quality of our teaching of statistical methods. Widespread use of statistical computing packages replaces derivations and hand calculation with an emphasis on concepts and realistic experience with data. There is clearly potential for improving theory courses as well.

The current emphasis on networking and communication makes another round of improvement possible, both in teaching and in developing course materials. I have begun the process of moving course materials from my file cabinet to computer files, most of which are open to students. I provide on-line copies of handouts, research and expository papers, software documentation, software command scripts and output (text and graphics) for course examples, grading policy, assignment policy, important dates, and an archive of all electronic mail that I have sent to the class. I hope in

the future to have all of my transparencies (graphics and text) available, both for ease of editing on my part and so that students can preview them or print them out. I minimize class time spent on course administration (referring students to the files instead) and use electronic mail for most announcements. Although I keep regular office hours, I implore students to ask questions electronically. When appropriate (which is often), I mail edited questions and my answers to the entire class. I rarely have to answer the same question twice, students appreciate the quick turnaround, and the archive file provides a ready outline for the improvements that I make to textual material, software, examples, and transparencies. Students like the system. Notice that it both improves my productivity and provides a framework for continuous improvement in the quality of my courses.

Future technology will permit more improvements in the quality of education, in particular through adapting instruction to the pace and learning style of individual students. It remains true, however, that new technology requires large investment both in equipment and in faculty time and effort, and that the proper use of new methods such as multimedia is as yet unexplored. In the current environment, adequate funding for large-scale implementation will become available only when there is clear evidence of improved benefit/cost ratios, not simply of educational effectiveness. It is easy to imagine, as David has done, technological means to serve more students with fewer instructors. Perhaps he is right in suggesting that traditional university education will become a luxury good, that we cannot compete on the basis of price. Yet in industry, changes in a process often improve both productivity and quality. Can we do likewise?

It is a bit frightening, but here is my vision of how this might be accomplished with technology. Imagine an extension of my computer-based course materials to include complete digitally-stored text material and lectures. Students can access a unified "courseware" data base containing video and audio showing an instructor, elaborate visual aids using both computer graphics and animation, video excerpts from *Against All Odds* and other sources, and other helps. The overall organization of the database is far from linear. Students can choose among several levels: review, basic required, extra-credit, and super-extra-credit. General-purpose instructional software links exposition at different levels to provide, at the student's request, more detail, more background (even linking to prerequisite course material, which will still be in the student's database), or more examples.

All of this resides on a student's notebook workstation. A large high-resolution display screen allows simultaneous viewing of and interaction with expositions in several media (text, video, audio, computer animation). Students can search through course materials for particular items. They can annotate exposition and problems with their own questions and notes, which are saved for future use. Help is available through a collection of frequently asked questions and powerful software to match the

students' question with the right answer. Questions not in the collection are forwarded wirelessly to the professor or an assistant. For non-standard or open-ended questions there may be more-or-less continuous electronic discussions with the professor as well as within and among student groups working on assignments and projects. Students can, with few constraints, progress through the course at their own pace.

How does the human instructor fit into this picture? The courseware system will do little more than replace textbooks and much of today's standard lectures. Professors will, as needed, organize and customize courseware for their particular course, add examples and exposition (audio, visual, or text), and choose the levels of material that students see upon taking various paths through the courseware. Professors with enough original material and good ideas will author courseware much as we now make our notes and examples into textbooks. Most importantly, instructors will meet with students in discussion or help sessions. Small-group meetings and personal attention will remain both desirable and expensive. The degree of personal interaction will—as it does now—reflect how much the student is paying in tuition. In the higher education system as a whole, however, there may well be fewer high-priced human professors. In this scenario, our future existence depends on our ability to provide cost-effective added value to future published materials that will go well beyond present-day texts.

2.3 Response by Joan Garfield

Although I'm enthusiastic about the role of technology in teaching statistics, I have reservations about the claim that we can maintain quality while greatly reducing the amount of human interaction. Human beings are by nature social, interactive learners. We check out our ideas, argue with others, bounce issues back and forth, and increase our understanding of ourselves and others. We learn through these interactions with other people (Meier 1992). In "Seven Principles of Good Practice in Undergraduate Education," Chickering and Gamson (1987) describe good teaching as encouraging student-faculty contact, cooperation among students, and active learning. Important components of good teaching include communicating high expectations and respecting diverse talents and ways of learning. The technological vision that Bill presents does not match this description of good teaching.

It is also not clear that technology-based teaching responds to the demands of the job market. Employers are increasingly asking their employees to work together cooperatively in teams. They want employees who can solve problems, think creatively, and have good interpersonal and communication skills. Too much reliance on a computer as a tutor and teacher may hinder development of these skills. We need to explore ways to incorporate technology-based team work into teaching, drawing on the teacher not merely to design the courseware, but to be an active facilitator of

group work and student learning.

It might be argued that computer networks can reinforce communications skills and (a new kind of) interpersonal relations. I doubt that electronic communications offer adequate interaction between students and teachers. Non-verbal clues are important, for example. The motivational advantage of working directly with a human being is considerable. A teacher gains insights about students by talking with, listening to, and observing them, and so can offer more effective feedback about their learning. This is true both for individuals and for small-group cooperative learning activities. Students can certainly work together via electronic networking. But a good teacher can observe and interact with student groups, facilitate their interactions, and deal with problems that arise. A teacher can encourage students to look at things from different perspectives, to compare solutions to a problem, and to develop respect for different learning styles and strategies, as well as emphasizing that there is not always one right answer. Where a computer might accept a correct answer and move the students along to the next activity, a teacher might challenge a group of students to try to solve a problem in a different way.

Although interactive multimedia systems hold promise for the teaching of statistics, they will not change the nature of beginning instruction in statistics unless other changes also occur. I think that new courseware and technology will have a positive impact on the quality (as opposed to the cost efficiency) of instruction only if teachers' views of statistics and the nature of learning statistics change substantially. Studies of mathematics teachers and how they teach have found that teachers' conceptions about mathematics and mathematics instruction profoundly affect both their teaching and the learning process. Similarly, how teachers view statistics (e.g., as a branch of mathematics with algorithms to follow, or as a science using tools to discover something about what data represent) and how they view teaching (e.g., delivering a fixed set of content to students or helping students construct their own understanding) affects what goes on in the classroom.

How can we encourage change? The National Council of Teachers of Mathematics has called for school mathematics teachers to reconceptualize their notions about the nature of mathematics and the way students learn (Feldt 1993). Simply knowing about new teaching strategies, including technology, is not enough. Based on an analysis of more than 200 studies in which researchers explored the ability of teachers to acquire new teaching strategies or improve existing skills, Joyce and Showers (1982) recommend that if teachers are to change the way they think about teaching their subject, they need to:

1. Study the theoretical basis or rationale for new teaching method.

2. Observe demonstrations by people relatively expert in the model.

3. Practice in simulated classroom settings.

4. Have opportunities for feedback.

5. Have coaching to provide feedback, companionship, and support.

I see a strong need for re-education of statistics educators and for specially designed education programs for future statistics teachers along these lines.

2.4 Response by George Cobb

Bill makes a strong case for technology, while Joan cites persuasive evidence that learning remains ineluctably interpersonal. Can we integrate their two approaches? In my pessimism I see an effective synthesis behind only one of three possible doors to the future. Behind two others, machines displace people.

One: High tech stays high quality. Across the country, mediocre lectures to hundreds of passive listeners give way to individual sessions with interactive computer-and-video-and-CD. This doesn't sound bad at all, but consider what else happens. Suppose development stays mainly in the hands of people like Bill Meeker and David Moore. All but a small number of the richest colleges and best-funded universities resist the temptation to build their own systems, and instead get site licenses to use one of the really good national curricular systems. In effect this turns the client institutions into satellite campuses of the big technology centers, and turns their faculty into glorified section leaders. Faculty morale drops, faculty status drops, faculty salaries drop, and faculty numbers drop. The quality of the live teachers' contribution to learning goes down, which makes live teachers look less and less necessary. We needn't follow the trend any farther, because people will see the handwriting on their hi-res screens before things get this far. Consequently, we are more likely to get what's behind Door Number Two.

Two: High tech goes downhill. This one is unmistakably a goat. Rather than turn into remote terminal clusters for Iowa State CPU, other colleges and universities try to build their own systems. They don't have the money or support, and most important, few have the vision and understanding to do it even halfway as well as Bill and David. Door Number Two opens out onto a virtual landfill of multi-mediocre techno-trash. If you don't believe me, just think about textbooks.

Three: High tech takes a human partner. Only after things have gotten painfully bad will we eventually decide that live, face-to-face interactions between student and teacher are important enough for the deeper kinds of learning that they are actually worth paying for, and that a good education uses technology to enrich but not replace more traditional approaches.

3. NEW WAYS OF HELPING STUDENTS LEARN

3.1 Provocation by David Moore

Americans are dissatisfied with the level of learning among students at every level below the Ph.D., and dissatisfied with mastery of quantitative concepts and skills in particular. Some of the dissatisfaction may reflect an unhistorical nostalgia for an imagined past, some may place on schools and colleges the burden of wider social changes, and some may result from the fact that skills acceptable in the past are now not employable. The customer dissatisfaction is there nonetheless, and one response has been a wave of reform in the teaching of mathematics. The gospel of reform goes something like this.

First, the confession of our sins: Traditional teaching appears to treat learning as transfer of information. Students learn by remembering what they are taught, and the teacher's task is to present information clearly and at the right rate. This assumes, often wrongly, that what the students take in is what the instructor thought she was putting out. What the students do take in is often a formal knowledge of facts and procedures divorced from intuition and from their knowledge of other subjects. The resulting knowledge is fragile—students cannot solve problems formulated in unfamiliar ways and cannot apply the facts and procedures they have learned to higher-order tasks such as analyzing open-ended situations and solving problems that require several steps and selection from a wide body of available procedures. In short, we leave our students with an algorithmic rather than a conceptual understanding. Few of us intend this outcome, but we must recognize that we often fail to achieve more. We teach as if we thought of ourselves as mere presenters of information.

After confession of sins, profession of the new faith: Students bring a complex mix of knowledge and intuition, both correct and incorrect, and learn by constructing their own understanding through interpreting present experiences and integrating them with their existing understanding. The teacher's task is to encourage and guide construction of correct mathematical understanding. Telling doesn't do this. Students must be active participants in learning. The teacher shapes an environment for learning through setting tasks, encouraging open discussion and group problem-solving, and insisting that students express clear conclusions from their work orally or in writing. (A number or graph is not a conclusion, nor are the words "Reject H_0.") Within this environment, the teacher serves more as a consultant and moderator than as a presenter, asking and showing rather than telling.

The new view is supported by research suggesting that active learning, group work, quick feedback and the like do (at least sometimes) improve learning. Garfield (1995) offers an exposition for teachers of statistics. Statistics is well placed to profit from these emphases. Working with data is an ideal setting for the new approach

to learning, so data analysis is becoming a standard part of school curricula. The practice of statistics involves a dialog with data rather than once-for-all analysis, contact with other disciplines, and a team approach, so the new style of teaching is easily accepted by those who want to bring teaching closer to practice.

The call for reform has been sounded by a succession of National Research Council reports, notably *Everybody Counts* (NRC 1989) and *Reshaping School Mathematics* (NRC 1990). It has aroused considerable opposition from supporters of the internal culture of higher education, who see it as a threat to the primacy of research and Ph.D. programs. The mathematician Saunders MacLane (MacLane 1993), for example, appraises reform efforts on the basis of whether they involve new mathematical ideas, attacks two deceased colleagues on the ground that they received tenure at Chicago "just for teaching," and says that the NRC reports on reform "remind one of the description of the School Mathematics Study Group (SMSG), an acronym standing for 'Some Mathematics, Some Garbage.' "

Undeterred either by Professor MacLane or by long socialization in the old culture, I have tried to change my classroom style in the direction suggested by the reformers. Here are a few observations. Your mileage, as the saying goes, may vary. I found the new style more effective with graduate students than with undergraduates; in smaller classes as opposed to larger classes; for teaching applied statistics rather than theory; and in courses where students could absorb the basics from the text, rather than struggling to read the book. In some courses I was satisfied that the students learned more, even though we "covered" slightly less material than in the past. In one course, on statistical theory for average mathematics undergraduates, the interactive approach flopped completely. The students were unsure of their mathematical foundations, had difficulty reading the text, did not want to talk in front of others, and resented being asked to do more work (as they perceived it) than in comparable courses. They wanted the clear lectures and careful structure their peers had told them I would provide. The only thing they liked was more frequent exams covering smaller blocks of material. As the semester progressed, I did more lecturing, to general approval.

I found change difficult on several levels. Years of student evaluations show that students think I'm a great lecturer; it's not so clear they think I'm a great discussion leader. That makes change psychologically hard. The new style is quite time-consuming. Preparing material for discussion and interaction takes longer than preparing clear lectures. Change was made harder by lack of organizational support—there was no local depository of resources, network of others trying similar innovations, or institutional decision to encourage reform. There was also no way to institutionalize successful innovations (I'll teach different courses next year). I learned once more the truth of an axiom of quality management: individual efforts without institutional commitment are difficult and have little lasting effect.

This is of course anecdotal evidence. But from conversation with other teachers I suspect that my experiences may not be unusual. Moderate changes (Fred Mosteller's "minute papers," more questions to the class, more student projects, more frequent assignments and tests returned very quickly) seem usually to succeed. More radical changes in what we do in class are risky. We are being told we must improve our efficiency to keep our costs down. We are judged on our "scholarly productivity." Active learning requires both more faculty time and a change in our habits, and student response is uncertain. A reasonable conclusion is that reform will make little headway among most faculty at most institutions.

I cannot imagine the reformer's utopia becoming reality. I say this without disputing their claims to higher quality. I'd like to have all students interact constantly in small groups with teachers skilled in the new style. I'd also like to wear hand-tailored suits. Neither will happen, for similar reasons.

I can, however, imagine real progress. Changing culture and better technology both hold promise. Technological optimists hope for stand-alone systems that will entirely replace human teachers. Educational reformers endorse technology, but rarely see it as even a partial replacement for human teachers. Surely the way of wisdom is to ask what human teachers do best and to apply technology to replace us where possible, thus conserving our expensive time for essential uses. Machine-made suits adjusted by a tailor do serve quite well.

> **Question 1:** Evolution is clearly more practical than revolution. What should we recommend that busy teachers actually do?

> **Question 2:** Is it at all likely that institutional change in the nature of college teaching will occur? How can we encourage change?

3.2 Primary response by Joan Garfield

As David points out, there is general agreement that we've got to do a better job of educating our students in mathematics and science. Although there is still some lingering skepticism due to the failure of past reform movements (e.g., the New Math), today's educators are searching for ways to dramatically change the way we teach these subjects. Much of the recent reform movement in mathematics and science education has been based on the constructivist theory of learning. As David notes, this theory explains the process of learning as actively constructing knowledge, which interacts with previous knowledge, beliefs, and intuitions. In practice, therefore, we should insist that students be actively involved in their own learning. Active learning activities are increasingly common in elementary and secondary schools, but the predominant mode of instruction in most colleges remains the lecture.

We are comfortable with lectures for many reasons. We ourselves succeeded as students in a lecture-based system. We have long experience in lecturing. We give lectures to our peers at our professional meetings and guest lectures at each others' institutions, settings in which information transfer really is our first priority. We ask candidates for faculty jobs to give lectures, from which we evaluate their lecturing ability as well as the content they deliver.

David's experiences when he moved toward more active learning are familiar to researchers on teaching. I would add that instructors who incorporate more in-class student activities also find that they have less control over the course, which may be discomforting to them. Their new role is that of a facilitator of and partner in learning. Class discussions do not always lead to predictable conclusions, and it may be hard to come to closure at the end of a class session and to stress the points intended to be learned that day. It is difficult to relinquish control without a clear sense of what is to be gained. Sometimes the rewards are clear. In other cases, both the students and instructor may be unsure of the advantages of abandoning the traditional lecture format.

Students' reactions to a nontraditional course format may not be uniformly favorable, as David experienced in his statistical theory class. When I changed my classroom style from lectures to small group activities, my teaching evaluations initially went down. Over the next two years, however, as I became more experienced and learned how to better construct and facilitate activities, my evaluations improved. I also received encouraging comments from students about how they enjoyed the class, how quickly the time went, and how much they learned from the in-class activities. Secondary schools and faculty in other disciplines are also experimenting with alternative instructional methods. As students encounter more classes where they engage in active learning, they will more readily accept this format in a statistics course.

The additional effort needed to prepare alternative instructional methods and to learn to use them well, combined with some frustration during the learning process, may be discouraging for teachers who often receive little reward for time spent on improving their teaching. These realities do not alter the fact, which I consider well-established, that lectures are relatively ineffective and that more active methods offer the hope of substantial improvement in learning. In order for real change to occur, instructors need to believe that it is important to change their teaching. I suggest that instructors who are not yet convinced that the traditional lecture approach should be replaced ask what it is they really care that students gain from their course. What ideas, concepts, and attitudes do they want students to take away? Then assess whether students have actually achieved these goals. The results may encourage them to consider changes in their teaching methods.

To specifically answer David's questions, I agree that evolution is more practical than revolution, and I think that evolutionary changes in college teaching of statistics

are already occurring. Evolution means gradual change over time, based on trying different approaches, keeping the ones that work, and abandoning the ones that don't. Many teachers are willing to change. What can we recommend to them? We can realistically recommend that instructors seek out and use the best available tools.

Practical implementation of new instructional methods depends on good teaching material so that busy teachers need not start from scratch. We need:

- Texts that students can read independently, so we can spend less time in class telling them what is in the book.
- Computer facilities and software that are easy for students to access, learn, and use, and that have the desired capabilities for learning statistics and analyzing data. As Biehler (1993) points out, good statistics software is not automatically good software for teaching statistics.
- Reliable activities that work well in class (with complete instructions for teachers). We need not just texts and software, but good data sets and class activities to use in provoking discussions and illustrating important concepts.

There are already better textbooks available, good software programs for students to use, and accessible collections of interesting data sets and activities. More materials will become available as they are developed by current NSF-funded projects designed to improve the teaching of statistics (see Cobb 1993). Most of these projects emphasize exploring data, through such means as collections of interesting data sets, design of in-class experiments, or development of software that is more appropriate for learning and understanding data analysis. Collectively, these endeavors reflect new emphases in teaching, and the NSF funding reflects a new level of concern for teaching. The availability of significant federal funds sends a clear message to institutions and departments: improving the teaching of statistics is important.

I agree with David that institutional change as well as individual conviction is needed if reform of teaching is to be wide-reaching. We all know the changes required. Colleges and universities must reward good teaching, successful educational innovation, and publications related to teaching. They must encourage experimentation through release time and other support. Professional societies should help make good resources known and available to educators. They should create and sustain networks of educators to share information, experiences, and resources, and to serve as support groups. They can establish awards that increase recognition of teaching. These systemic changes are in fact underway. How far and how rapidly they will proceed remains uncertain.

3.3 Response by George Cobb

I, like David, find myself convinced by the theory, converted to the new faith by the testimonials of Joan and her colleagues. But I also share David's pessimism about the chances for change. The new labor-intensive teaching costs too much, especially when money is tight and technology offers ways to replace faculty with less expensive objects for students to interact with.

As individual faculty we are attracted to the various reforms in order to improve the *quality* of student learning, but as individuals we tend not to institutionalize the changes we make, especially if they are mainly changes in the patterns of our interactions with students. Most administrators and politicians and parents are more concerned with the *cost* of education than its quality. To them technologically-based change has more appeal than interpersonally-based change because technology promises to enable fewer faculty to teach more students. Reduce contact hours, raise the faculty/student ratio, and you can keep tuition down. I believe we'll see much more of this, because the gains in efficiency are much easier to measure than the losses in quality. In fact, the most important loss—all those expensive hours of face-to-face contact between student and teacher—is generally regarded as a gain in efficiency.

Keep in mind that across the country, the huge lecture is the exception, not the rule. Nationwide, roughly 80% of the classes in elementary statistics have fewer than 40 students. So when budget-balancing administrators substitute technology for faculty, we will lose mostly small classes with lots of faculty contact. Not by coincidence, these are precisely the situations in which David's observations show the new approach to be most effective.

3.4 Response by William Meeker

I understand and agree with what Joan and others are saying about active learning and the weaknesses of the traditional lecture format. However, I do not agree that we should do away with lecturing altogether. The most effective learning occurs outside of class time when students are working problems and doing projects. After all, one of the things we aim to teach college-level students is that they must learn on their own, that knowledge need not be spoon-fed. In class we should do whatever best facilitates out-of-class learning. I expect that the optimum mix of lecture and other classroom activities varies with the nature of the course.

I am modestly optimistic about the reform of teaching. I think it likely that we will make steady progress based on gradually accumulating information. We will certainly see both successes and failures, and both will contribute to learning about our educational processes. We will see continuing development of new instructional materials. We will see better means of sharing information, such as the new electronic

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Effective encouragement for change clearly requires not exhortations but:

- Convincing demonstrations that change is beneficial and not too painful to implement.
- Ready availability of instructional materials that make change less painful.
- Changes in the academic rewards structure that will better reward professors who endure the pain to achieve significant improvement in their courses.

All are happening. Whether they will happen rapidly enough to ward off very unpleasant cost-based forced systemic change is unclear. We can't stay as we are, and we would do well to work hard while we still have some influence on the direction of change.

3.5 The audience responds

At this point in the session, members of the audience were asked to form small groups to discuss the issues raised about teaching. We asked them to write down the issues they felt to be most important and to turn them in to be summarized in our written paper. Most of the written comments agreed that real change in statistics teaching is needed, and many asked for help in bringing about change. The respondents wanted new materials to use in teaching, and they wanted ways to more easily learn what other teachers have developed or tried in their classes. They also wanted guidance in the use of alternative pedagogical approaches, such as small group work and new forms of assessment. Many spoke of the need for change at higher levels, calling for the elimination of the "publish or perish" standard and for substantial changes in reward structures so that faculty who spend time developing and implementing innovative teaching efforts are better recognized and rewarded.

4. HIGHER EDUCATION UNDER SIEGE

4.1 Provocation by David Moore

Important institutions always have their critics. Nonetheless, the intensity of criticism directed at higher education—-and in particular at research universities—in recent years is unprecedented. Popular books refer to "illiberal education," to "tenured radicals," to "profscam." Leading business magazines print articles that abandon all pretence of respect: "The time is long overdue for someone to say to the faculty:

'You turkeys have had a free ride for too long. You were hired to teach. Do it!"' (Sowell, 1994) The public replies of college presidents have an increasingly defensive tone. Parents and legislatures question the dominance of research over undergraduate teaching and the apparently light workload of faculty. They also note that many college graduates can't find good jobs, and that the direct contributions of colleges to solving social and economic problems are not impressive. Allegations of fraud and scientific misconduct by the most eminent institutions and individuals (Stanford, David Baltimore) receive national publicity. There is incoming fire from all directions (I didn't even mention athletics), with enough direct hits to do real damage. "Accountability" is in fashion. Money is scarce, and so is public support for maintaining our share of the pie.

This criticism reflects a clear clash between the cultural norms of university faculty—norms that we hold almost unconsciously—and the missions that those who pay our salaries have in mind. Our customers want attention to undergraduate teaching (with some mixture of education and career preparation), expert help with all manner of societal problems, and direct contributions to technological advance and economic development. In the case of many public institutions, contributions focused on state and local needs are especially valued. These customer demands do fit the teaching–service–research scheme that public universities traditionally use to describe their missions, but the faculty interpret these missions quite differently.

Faculty culture in the sciences in research universities is characterized by disciplinary specialization and by intense work on problems of our own choosing. (The public thinks we don't work very hard because they don't see or don't value much of our work.) This system is perfectly suited to encourage fragmentation and to discourage collegiality, loyalty to our institutions, interest in state or local needs, and attention to broader issues whether scientific or societal. We believe that we are entitled to society's support for research driven by the inner evolution of our specialized disciplines and are convinced (on weak evidence, and despite the Japanese counterexample) that such research does efficiently foster technological innovation, economic development, and job creation.

If this faculty culture were confined to a limited stratum of institutions, few would complain—after all, the research universities can point to great accomplishments. But service on various Washington panels has made it clear to me that every institution called "university" considers itself a research university. Moreover, four-year colleges increasingly assess their faculty (who were trained and acculturated at research universities) by similar standards. Society cannot reasonably support the aspirations of so many, so we feel neglected. As Leon Lederman said in his presidential report (Lederman 1991) to the AAAS, describing a survey he had commissioned:

> The responses paint a picture of an academic community beset by flagging

> morale, diminishing expectations, and constricting horizons. From one institution to the next, across demographic categories, across disciplines of research, the nation's scientists are sending a warning. Academic research in the United States is in serious trouble.

Lederman's solution is simple: "a doubling of the current level of funding for academic science and an annual growth rate of eight to ten percent." Given that government support in real terms is already at record levels, this is both unrealistic and selfish. I cannot imagine a future in which society continues to satisfy our expressed needs.

I can imagine a new culture within higher education. So can many others. Here are recommendations from a panel chaired by outgoing presidential science advisor D. Allen Bromley and Princeton president Harold Shapiro (Anderson 1993):

> (The panel said) it is "unreasonable to expect that the system of research-intensive universities will continue to grow" ... As a result, the panel concluded that it is "ill-advised" for such universities to "aspire to excel in all or most areas of scholarship." Instead, they should focus more on teaching, even though "in doing so, many institutions will have to curtail some of their research activities." And it calls on universities to apply a scalpel instead of a cleaver, cutting low-priority and low-quality projects and concentrating on the research they do best.

Most thoughtful commentators seem at last to concede that there is some conflict between research and undergraduate teaching. University presidents have redoubled their public statements about the importance of teaching. I pointed earlier, in speaking both of technology and of new styles of helping students learn, to the difficulty of promoting lasting change when innovation is left to individual faculty in individual courses. Now external pressures are demanding *institutional* change.

> **Question 1:** Are we at the beginning of a national re-emphasis of the importance of teaching in colleges and universities?

I can imagine a new culture. But getting there from here is the domestic equivalent of reforming the Russian economy. Our present culture is not equipped to resolve conflicts among disciplines, so deciding which are the "low-priority and low-quality projects" invites internal warfare. The almost certain answer is that, as usual, quality will be measured by external funding. We can guess that faculty who are concentrating on the research the institution does best will be paid 50% more than those suddenly second-class individuals who must now focus more on teaching. Yet there are some hopeful signs as well, not only public statements but apparent changes in

hiring patterns and even in standards for tenure. Cornell, in a change of policy that says as much about the prevailing system as about new beginnings, "has decided it will not approve tenure decisions unless they include a thorough assessment of teaching ability." (DePalma 1992)

> **Question 2:** What in particular does the unstable state of higher education portend for statistics?

Statistics is a particularly interesting case. We have several advantages. Statistics has a substantial presence (larger than mathematics, for example) outside academe. We can offer direct contributions to problems of visible value to the public and to politicians. Training in statistics has job market value to students in a variety of disciplines. Simultaneously, an understanding of data and chance is increasingly recognized as one of the central intellectual competencies that a liberal education should foster, so that as core curricula return to fashion they often include a quantitative literacy component.

On the other hand, statistics is a small discipline within higher education (much smaller than mathematics, for example). It is not seen by other academics as a central or essential discipline. And in most institutions statistics is taught by a variety of academic units. Statistics departments are therefore, as ASA President Ronald Iman has noted (Iman 1994), plausible victims of the power struggles among disciplines that the new environment is bringing. I predict that political weakness will overwhelm disciplinary strength, and that some major universities will soon dismantle their statistics departments.

4.2 Primary response by George Cobb

Are we about to see a major national reemphasis on teaching? Bears will use indoor plumbing first. Whether for bears or academics, there's no economic incentive to change. My pessimism trickles down from the dismal twin clouds of supply and demand:

First, supply: There is a cultural analog of Gresham's Law that implies that bad research drives out good teaching. Money and status flow toward activities whose consequences are concrete and short-term, like a paper published, rather than vague and long-term, like a mind enriched; toward activities where responsibility and authorship are clear cut and limited to a few, as in research reported in a journal, rather than shared in a vague way among a host of contributors, as in teaching. Working with *things* pays better than working with parts or aspects of *people*, and working with the *whole* person pays even less. Thus the corporate bond lawyer out-earns the criminal lawyer, the surgeon out-earns the pediatrician, the medical

technician out-earns the day care worker, the researcher out-earns the teacher, and—let the parallels fall as they may—the garbage collector out-earns the parole officer. I know of no important exception to this general phenomenon, and I don't expect higher education to provide one any time soon. Good teaching will continue to be in short supply.

What about demand? If supply refers to teaching, then demand must refer to learning. Are we about to see a national re-emphasis on the importance of *learning*? I'll grant that, as reflected in our national political discourse, the demand for genuine learning probably exceeds the demand for ursine plumbing fixtures, but the race is too close for comfort. Or, to forsake the imagery of Smokey and Yogi for that of industry, what we hear about education these days is mostly bean-counting language: about efficiency (the cost per student passed through) and accountability (scrapping the bad people or products after the dastardly deeds are already done) rather than about working cooperatively with meaningful data and constancy of purpose to improve the underlying process. Teaching and learning pertain to the *quality* of education. Eventually, I *do* expect market forces to create a new demand for learning, but not until we have reexperienced the pain of many American manufacturers. Meanwhile, we'll keep trying to do it cheaper until we're forced to do it better.

If the economic outlook for teaching is generally bearish, is there any bull to be found by narrowing our focus to statistics, in the context of the general instability within higher education? I find David's analysis in terms of intramural political dynamics and extramural dynamics of a more general sort to be clear, instructive, and, best of all, grounds for optimism.

Statistics is, as David says, smaller than mathematics within our colleges and universities. In fact, more statistics (the subject) is taught in mathematics than in statistics (the academic department). According to a recent survey by the Conference Board of the Mathematical Sciences, for every section of elementary statistics taught in a statistics department, there are roughly five sections taught in mathematics departments (Albers, *et al.* 1992, p. 54).[1] Moreover, strong trends suggest that statistics may (as it should) replace calculus as the capstone mathematical study for many students. Here, again from (Albers, *et al.* 1992) are data on statistics enrollments in two-year colleges as a percentage of calculus enrollments:

Year	1966	1970	1975	1980	1985	1990
Percent	10	19	37	27	36	52

These data also reflect David's observation that statistics is larger than mathe-

[1] In fall 1990, 1781 sections were taught in departments of mathematics, only 364 sections in departments of statistics. These data, a corrected version of numbers reported on p. 54 of Albers *et al.*, are for universities and four-year colleges. If two-year colleges were included, the imbalance would be even more extreme.

matics in the world outside the academy. Were it not for the real-world need for statistics, mathematics departments would not be offering so much of it in place of topics dearer to the mathematical heart. The data suggest that the perceived need for statistics in the real world is a force more powerful than the political muscle of those who would rather shift resources from statistics to other subjects. Statistics departments may be endangered, but statistics itself, and the teaching of statistics, are not. May I point out that only two of the four authors live in statistics departments?

4.3 Response by William Meeker

A colleague who took his first position at a major research university 20 years ago told me that the advice he received from his major professor was "Do just enough work on your teaching so that students don't complain to the department chair. Spend all of your other time on research." I'm pleased to observe that the optimal strategy for attaining tenure and promotion is changing. Yet I wonder how much weight we are willing to give to truly outstanding teaching performance when coupled with a middling research record? Part of our culture is, after all, that research universities depend heavily on outside research support, especially for their graduate teaching programs. Universities that change the focus too much from research to teaching are taking a risk.

With respect to David's second question, I agree with George that statistics as a subject will not disappear. There is, however, a real danger of local and perhaps global absorption. Statistics as a distinct discipline *is* at risk. Many universities have never had a department of statistics. Many, perhaps most, departments of psychology, business, sociology, and engineering offer courses in statistics. The instructors of these courses often have limited formal training in statistics, but in some cases are knowledgeable and competent because of their practical experience. Physicists, engineers, and chemists in universities typically do their own statistics, often with surprising sophistication. Because these scientists are well trained in quantitative methods, they often perceive seeking out a statistical consultant as a sign of weakness. Statistics departments may, especially in times of shrinking resources, be viewed as expendable.

What can we do to maintain and improve statistics' state as a discipline within the universities? We need to listen to our customers. These customers include our students, other departments that apply statistics in their subject-matter courses, and the potential employers of our students. We need to give our customers what they need rather than what we think that they need or what we want to teach. We cannot count on these customers to come to us with their needs. We must be proactive in getting the needed information and marketing our improved products.

5. UNCERTAIN FUTURES

Our stress on the broader trends that will certainly bring rapid changes in our little subject—the teaching of statistics in colleges and universities—is appropriate in a *fin de siècle* exercise in imagination. Yet we should by no means be entirely pessimistic. Statistics and statisticians have resources that may enable us to prosper as we serve our students and others. Technology may at last really change higher education, but because our professional practice is already based on technology we can welcome technology in our teaching. New styles of learning require active involvement of students in learning and interaction between teachers and students, but because statistical practice is active and interactive, it is easier for us to change our classroom practice. Colleges and universities may be forced to give more attention to preparing undergraduates and to broad societal needs that cross the boundaries of research disciplines, but statistics is inherently interdisciplinary and oriented toward analysis of complex problems.

We therefore do not wish to conclude on an apocalyptic note. Within the academic ecosystem, statistics is as robust and vigorous as the dandelion. The subject may not always be deliberately cultivated by those who oversee the garden, but its intellectual seeds are nearly always in the wind somewhere, which means that no department's back yard is safe from it. Once established, it grows deep, so that even if you try to yank it up, you only get what's visible at the surface, like an occasional professor or two. The roots of statistics are still there, and before long, it will come back.

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