The Calculus of Education Reform

New teaching methods promise to revitalize a dull course, but students raised on tradition remain skeptical; their reaction holds broad lessons for curriculum reform

Durham, North Carolina—IF YOU REMEMBER calculus as the class that all too often seemed to consist of your college math prof droning on endlessly about integrating quadratic equations, drop in on an experimental new calculus class at Duke University and brace yourself for a shock. You won't see a lecturing prof or blackboards full of problem drills—nor will you see any students snoozing in the back while their confrères busily scribble notes. What you will see at 9:02 on a Tuesday morning are students working away in teams of two, making the relationship between variables spring to life in computer graphs as they use real-world data to investigate such problems as world population growth.

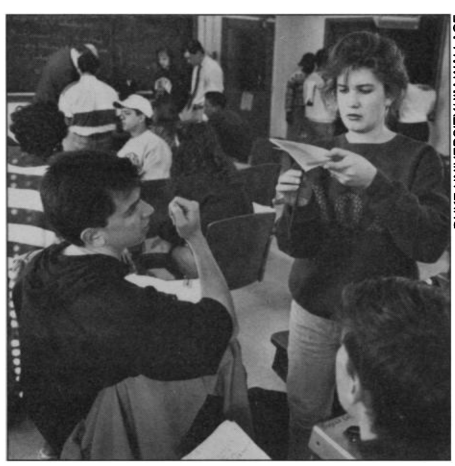
You might think you have stumbled into the wrong classroom. In fact, that's a common feeling among Duke students, who find themselves alternately frustrated, intrigued, and bewildered by this newfangled way of teaching calculus. But they may have to get used to it. Radically different forms of calculus classes are springing up everywhere in U.S. colleges and high schools as part of the education reform movement that is trying to elevate American students from near the bottom of international league tables of science and math achievement. (Just last week, the National Science Foundation reported that U.S. 13-year-olds ranked 14th out of 15 countries in mathematics performance, just ahead of Jordan.) The mixed reaction to these experimental calculus classes should hold some lessons—and warnings—about how this broad reform movement will play among those who count most: the students themselves.

Among educators, interest is intense. Reports from trial courses draw crowds of curious mathematicians at national meetings, and E-mail hums with anecdotes and advice. All this is a far cry from 10 years ago, when almost every college relied on the same basic calculus syllabus. "I used to say, 'You tell me what week of the term it is and the book they're using and I'll tell you where they are.' And I didn't really need to know the book," says George Rosenstein, math professor at Franklin and Marshall College in Lancaster, Pennsylvania, which is implementing a more modest calculus reform.

At this point, it's too early to say whether the still-evolving experimental courses can do a better job than a good traditional class. And if the reactions of the Duke students are any guide, reformers may have a tough job winning over the student population. Of course, traditional calculus classes weren't earning rave reviews from students, or from their professors for that matter. Over the past decade, faculty in both math and the sciences have begun to recognize that the old ways were simply not working.

Calculus has long been the gateway to careers in science and engineering, but too often that gate slams shut. In first term freshman calculus, about one-third of the students get a D or worse, according to a study published by the Mathematical Association of America in the late 1980s. And science faculty complain that even students who do well can't apply what they've learned.

So in the late 1980s, the calculus reform movement was born in several conferences sponsored by mathematical societies and private foundations. In 1988 NSF weighed in with funding for new ways to teach calculus and has awarded nearly $11 million to date. The Duke project, entitled "Calculus as a Laboratory Course," or simply "Project Calc," is one of the leading beneficiaries and will receive more than $900,000 from several NSF offices for the period 1988 to 1993.


DUKE UNIVERSITY/JIM WALLACE

Group learning. *Project Calc classes rely heavily on collaborative projects.*

Although reformers began with a multitude of approaches in 1988, they already have begun to converge on a few common themes, says Deborah Hughes Hallett, co-director of another project, the Harvard Calculus Consortium. For example, most of the new courses focus on understanding calculus in three ways: algebraically, graphically, and numerically—what Harvard types have called the Rule of Three.

The new courses also incorporate writing, stress mathematical experimentation, foster teamwork, and in many cases rely on computers and graphing calculators. There's less memorizing and more thinking about real-world problems. The goal: to get students to understand what they are doing instead of just solving problems by rote. The projects still differ in emphasis, but Project Calc, which is up and running at 10 sites in addition to Duke, incorporates all these themes and illustrates the common spirit of reform.

The students still have thrice-weekly class periods, albeit with few of the old-style lectures. Instead, the students may use the time to work together solving problems. But the heart of Project Calc is the laboratory, where students meet for an additional 2 hours each week.

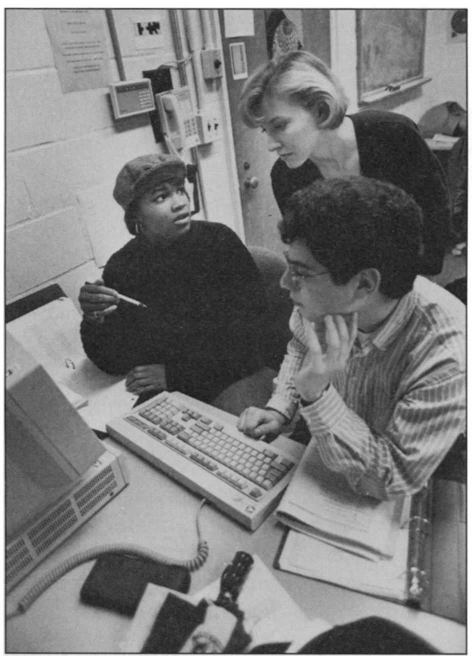
In one lab, for example, students tackled world population, exploring which of two mathematical models best fit population growth to date. They plotted real data against time—or rather, they ordered their computers to plot the data swiftly for them. Then they graphed the same data on semilog axes, to see if the points took the shape of a simple exponential function in which the population doubles at a steady rate over time—and which graphs as a straight line on semilog axes. The colored points lighting up the computer screen clearly showed that a straight line model wouldn't do—the population was increasing too rapidly. So the students turned to the second model, an even more steeply rising super-exponential function that seemed to fit the data better. They then used the data to estimate the parameters of this function and also algebraically solved its differential equation.

The whole idea is to reinforce two central concepts, say Project Calc directors David Smith and Lawrence Moore of Duke. First, that the slope of a curve equals rise over run.

And second, that a derivative is a rate of change, which can be expressed in a graph, in algebraic symbols, or as numbers.

Those concepts are hammered home in different ways week after week, but students still stumble over them, says Smith. But in a traditional class, a student might get an A without understanding such concepts at all. "Ask traditional students what a derivative is and they'll describe a procedure," says Jerry Uhl, who helps direct yet another star project at the University of Illinois. "They don't understand it as a rate of change."

When students finish a lab, they have to write an explanation of what they've done and what it means—in good English. That's a major departure from tradition and a critical part of the new approach. "You can tell if they understand by whether or not they can explain it," says Mike Reed, a professor of math at Duke who taught one term of Project Calc. Although Reed doesn't endorse every detail of Project Calc, he's a big fan of several parts of it, especially forcing students to work together. Since much of



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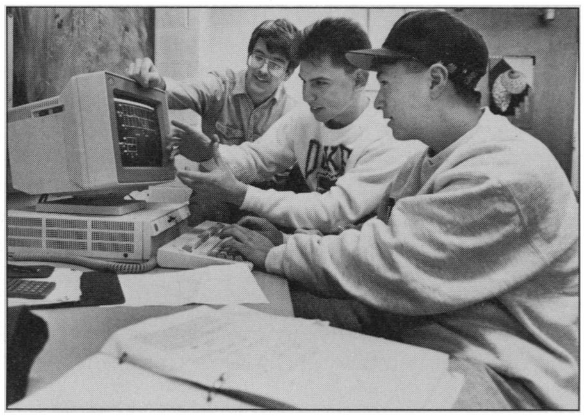


Bringing data to life. *Computers are used to explore real-world problems such as population growth.*

their grade depends on co-authored written projects, students have to collaborate both during lab and outside class. And so they befriend each other.

Making new friends while tracking world population growth sounds like much more fun than repetitive homework problems and frequent quizzes. But students don't necessarily think so, at least to begin with. Course evaluations show high levels of student dissatisfaction, though students who stick with the course for two terms seem to become converted. But so far at least, Project Calc has failed at one goal of the reform projects—keeping more students in class. Last year only 56% of Project Calc students went on to take a second term of calculus, compared to 68% of students in traditional calculus.

Sophomore Tom Felgner switched to a traditional section after one term of Project Calc last year. "Worst class I ever took," he says of the experimental course. Another student wrote on a course evaluation, "I wish I had to memorize more. I'm sick of real-life models." Complained another, "I am very jealous of my friends in normal calculus. I would do anything to have taken regular calculus with a pencil and paper."

Duke freshman Mary Harris, who likes math and is considering becoming a math major, sums up Project Calc this way: "It's a big exercise in confusion." Students like Harris worry that they "aren't learning any math." In an attitude survey of a small sample of Project Calc and traditional students, the biggest differences showed up on questions such as whether the course "taught the basics of calculus." Traditional students thought they were learning "real math," while Project Calc students weren't quite sure what they were learning. Project Calc students also gripe about the workload, which Smith and Moore admit is heavier than in traditional calculus, and about a teaching style called discovery learning. When asked a question, Project Calc instructors typically respond with another question. This drives some students crazy. "God, I hated that," says Felgner.

In response to student criticism last year, Smith and Moore lightened the workload significantly by requiring fewer lab writeups. But in general, Project Calc backers say students are griping because the new course doesn't fit their notion of a math class. Student discontent at Duke simply illustrates the hard facts of education reform, says Smith: If you change the way students learn math, they'll put up a howl, even if they weren't too crazy about the old way.

The students who protest the most are the ones who did the best under the old system—namely students at Duke and other elite institutions. "These kids have been really successful at school, under the old rules," says Jack Bookman, a Duke math instructor who is evaluating Project Calc for NSF. "Now they're pissed off, because we changed the rules on them." For example, the Harvard project uses the same course materials at a variety of small liberal arts colleges and community colleges, as well as at Stanford and Harvard. "And it's at Harvard and Stanford that the students say, 'This is too hard! You haven't told us how to do these problems,'" says project co-director Hughes Hallett.

Duke students who don't like Project Calc do seem to be yearning for the good old days. "That book," says Felgner, speaking of the Project Calc textbook. "There's no answers in the back. A normal math book has answers in the back. The best way is to get the answer and work backwards. That's how you learn to do the problem." Harris, the freshman now in Project Calc, longs for the simple pleasure of working a problem and making it come out right. "We need to do more basic problems," she says.

Although Smith and Moore are gradually reinstating a little more computation to give students a sense of mastery, in general reformers have little patience with such complaints. "What they're longing to do is not problems but exercises, which is what they're accustomed to, a whole series of straightforward bite-sized exercises instead of a bigger project. That's like only learning to write sentences in an English class, never writing an essay," says Lynn Steen, professor of math at St. Olaf College in Northfield, Minnesota, and chair of the steering committee for a new NSF-sponsored evaluation of the whole calculus reform movement.

Students can be won over to the new courses, however—given enough time. Student opinion on Project Calc takes a turn for the better in the middle of the second term, reports Smith. They seem to understand finally what the course—and the subject—is all about, and the tone of course evaluations changes dramatically. "I believe I learned more in this class than I ever learned before," wrote one. Asked to compare themselves to their friends in regular calculus, students are clearly more confident. "We learn more. We can explain the concepts better," wrote another. Crowed a third, "I can take their tests but they are clueless on mine." And one keen observer noted, "Too many people in Project Calc are unhappy for being forced to think."

At Duke next fall, all first term calculus classes will be in the Project Calc mode, which is expected to lessen the complaints. But even if the students can be coaxed into appreciating a new style of learning, calculus reform still faces resistance from some faculty who are not yet convinced that such radical changes are necessary. Also, Project Calc demands a considerable time commitment from instructors as well as students, plus resources such as computers, lab rooms, and extra teaching assistants. Other reform efforts, such as the Harvard Project, are less expensive because they do not require computers. Still, some reformers worry that the climate of retrenchment at universities may make reform a hard sell.

The big question is, of course, whether the reforms are worth the costs in effort and money. Although it's too soon for strong statistical evidence, students in the experimental courses do seem to have a better grasp of concepts, says evaluator Bookman, who plans to track the majors and grades of Project Calc students. On a preliminary test he gave to both types of classes, Project Calc students were much better at putting a word problem into the form of a differential equation, for example. Other project directors cite science professors who were pleasantly surprised by students' understanding of such things as logistic growth or the normal distribution curve. And after sitting in on both traditional and Project Calc classes, Bookman offers another snippet of anecdotal evidence: In the traditional class, someone dozed off every week. In Project Calc, students might be frustrated or confused, but at least they don't go to sleep. And students say they rarely miss class or lab. "It's the one class I never skip," says Duke freshman Greg Cancilla, who thinks Project Calc is okay but too much work. "You miss this class, you're clueless."

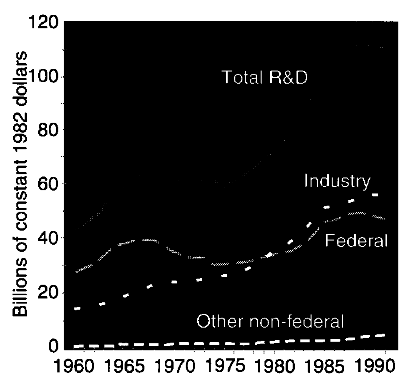
These sentiments are encouraging. But the experience so far with Project Calc underscores just how difficult the process of education reform can be—even for the best and brightest students. ■ ELIZABETH CULOTTA

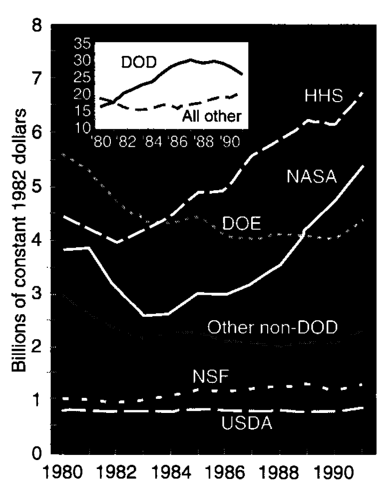
U.S. R&D Spending: Half Full?

The tenth edition of the National Science Board's (NSB) biennial compilation of statistics on the U.S. research and development enterprise, *Science and Engineering Indicators*, provides further proof that nearly every point of view can be credibly supported with the same set of figures.

The report shows that inflation-adjusted spending on research and development, including both federal and industrial sources, has declined slightly in the last year or two after a decade of steady growth (see chart). "[A] slowdown in research expenditures in industry and academia and problems in education should give us real concern for the continued vitality of our research enterpise," says James Duderstadt, chairman of the NSB, in a statement that accompanied the release of the report.

But Leonard Lederman, who studies U.S. research performance at the National Science Foundation (NSF), notes that one reason for the decline is a drop in Pentagon spending. Moreover, in view of the global recession and continuing high deficits, "leveling off" is practically good news, says Lederman—especially when compared to other segments of the economy. "'We're holding our own' is a better perspective than, 'We're going to hell in a handbasket,'" Lederman says.





Leveling off. *Total R&D spending has plateaued* (above) *largely because Pentagon R&D outlays have declined* (left).

The report, produced by the NSF's Division of Science Resource Studies for the NSB, does depict some worrisome trends that should help officials from science agencies defend their proposed budget increases, however. It shows, for example, that while the United States spends more on nondefense research than any other country in the world, as a percentage of the gross national product it is below that of two of the nation's most important economic competitors—1.9% in 1989 (the last year for which data are available), compared to 3.0% in Japan and 2.8% in West Germany. The picture in the private sector is no better. Spending on R&D by industry also dipped recently, after 30 years of nearly constant real growth. That is sure to be highlighted this spring when the Administration tries to persuade Congress to support a permanent tax credit for industrial R&D.

Universities should also be able to use the report to bolster their claim that the federal government needs to do more to support academic research. Not only has the federal share of academic R&D costs been declining steadily for the past 20 years, but the report suggests that new spending money for capital expeditures has come primarily from nongovernment sources.

In addition to figures on R&D spending, the 487-page report surveys a wide swath of U.S. science and engineering activities:

■ **Output**. U.S. scientists still lead the world by a large margin in the number of scientific papers they produce.

■ **Education**. Pre-college math and science performance has not deteriorated, but still does not compare favorably with many other countries. In higher education there were declines in the number of baccalaureate degrees in the physical and life sciences but, overall, small increases in the total number of degrees in science and engineering over the past decade.

■ **Public attitudes toward science**. More than three-quarters of the public still supports federal spending on research "even if it brings no immediate benefit."

■ **Trade**. During the 1980s Japan increased its share of the global high-tech market from 18% to nearly 27%, while the United States and the European Community each saw its share of the same markets decline by 4%. ■ JOSEPH PALCA