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# What They Didn't Tell Me About Calculus and the Computer

Mel Henriksen UME TRENDS Dec. 92

My first attempt at using computers as an aid to teaching calculus began in 1966 and culminated with the publication in 1971 of *Single Variable Calculus*, written jointly with Milton Lees. Everyone used a mainframe and punched cards and few knew how to program. Computer use was limited to supplementary exercises that could be done today with a hand-held programmable calculator. A constructive sequential approach to limits and elementary numerical analysis were emphasized. The absence of programming displeased computer scientists, but it was too avant garde for all but a tiny minority of teachers of calculus. Attempts by others of this sort failed as well, but I believed then, as I do now, that the teaching of mathematics must take into account the revolution in our society created by the existence of electronic computers.

The appearance of personal computers in 1981 changed the rules of the game by freeing the educational user from mainframes. Programs that could quickly produce graphs of complicated functions in two or three dimensions were developed along with symbolic manipulators at affordable prices. Simultaneously, traditional calculus courses came under attack on several fronts. Some urged that calculus take a back seat to the teaching of "discrete" mathematics, others felt that calculus ate up too much time in the curriculum, and almost everyone was concerned with its huge mortality rate. CALCULUS REFORM became the rallying cry of the decade, fueled by infusions of money from federal and private sources. The development of large scale, user-friendly, menu-driven programs such as *Derive*, *Maple*, and *Mathematica* with symbolic manipulating capabilities made many believe that using computers to help teach calculus would revive student interest and overcome the ravages of poor high school preparation.

Papers on calculus reform at national meetings did little to revive my enthusiasm. I heard tales of "successes" bought at the price of the teacher working three or four times harder than usual with no realization that favorable student response might be the result of extra attention instead of the use of computers. Some rejected menu-driven software and felt that only by doing their own programming could students be broken of the habit of blindly memorizing algorithms, without saying where the time would come from to teach students how to write elaborate programs.

My cynicism was overcome when I saw the *Calculus and Mathematica* (C&M) materials developed at the University of Illinois by Professors Porta and Uhl (together with a set of co-authors that varies with time). These materials enable students to learn to use *Mathematica* as they do mathematical problems. The more elaborate code can be copied from text materials on discs and pasted into solutions of problems, reducing the amount of time spent on programming. The bias of the authors is that calculus is concerned with calculating. The downside is an absence of precise definitions and clearly stated theorems. The upside is a large number of concrete problems that force the student to think about "theoretical" topics to solve them. The students were expected to learn both mathematics and *Mathematica* by doing. The center of learning is the Computer Laboratory where students work with a minimum of reliance on the instructor or listening to lectures. I was sold on the idea and resolved to fill in the missing theory on the side.

Harvey Mudd College has an enrollment of 600, in which all of the students enter with high SAT scores in mathematics and must major in engineering, mathematics, or science. A lot of support was given to this course. We had access to 15 MacII's equipped with *Mathematica* and two of us worked for a month, together with a student with expertise on Macintosh and *Mathematica*, to prepare to teach in this new way. The Mathematics Department hired student assistants to help the entering freshmen (and us) with *Mathematica*

and we started the fall semester of 1991 with 52 volunteer students, an overcrowded Mac lab, and a mixture of fear and enthusiasm.

The results were mixed. Some took to *Mathematica* like a duck to water while others found learning it painful, but all of them mastered it well enough in a few weeks. Some loved the freedom provided by the C&M materials, but many came to class with notebooks open and pencils poised to copy explicit instructions on which algorithm to apply to which homework problem and resented having to read text materials or cope with open ended problems. We had little intuition on how long it would take students to do an assignment and our initial ones were too long. The computer lab was inadequately supervised and hackers would at times make it difficult for our students to use the Macs. Our network was too small for the volume of homework and the Macs broke down often, resulting in understandable student frustration and irritation. The crowded conditions in the Computer Lab discouraged students from bringing text materials or pencil and paper. Students typed with little thought and spent too much time trying to use *Mathematica* to carry out calculations more easily done without it. (No symbolic manipulator has a terribly good simplification routine.) Improvements were made with time in the server and networking, but troubles continued to plague us. Grading even a fraction of the homework was an overwhelming burden even with additional help from the department chair.

What should "they" have told us? Every educational experiment has pitfalls and nobody can warn you about all of them all in advance. The answer is an adequate warning about the preconditions needed to carry out such a program, especially what is needed by way of computing equipment and its care and feeding. We did not realize how vitally important it would be that the lab be uncrowded so that students could look at written materials and carry out pencil and paper calculations. We were not warned how often and easily breakdowns of the Macs or equipment associated with them could take place

I have no doubts about the honesty of the missionary zeal of Porta and Uhl about the C&M materials and their program, the care and thought that went into devising the excellent and thought-provoking problems, or about their ability to excite many students. As practical people, they (and champions of other programs) must obtain funds from foundations and attract a publisher to continue their program, and they cannot do so by equivocating. Educational innovation has become a consumer product that must be marketed. Almost all reviews of materials designed to teach courses in mathematics with the aid of computers are written by experts and seem addressed to aficionados. All too few of them indicate what kind of support is needed to run such courses or hint that they might not be good for every student. Any teacher learns with experience that no single mode of instruction will work well for all students, but the sudden availability of money pushing some particular brand of "reform" tends to blind us to this fact of life. Most college administrators regard faculty who get grants as superior to those who do not.

Emotion as well as money can cloud our judgement. Almost all of us find teaching calculus demanding and frustrating. We have strong differences on what the content should be and stop discussing them after a while to keep the peace. Yet we talk about THE CALCULUS as if this term were well defined and the air is filled with assertions claiming either that using a computer in teaching calculus can only result in the watering down of the mathematical aspects of this course, or that anyone who refuses to jump on the computer-and-the-calculus bandwagon is both lazy and old fashioned. Hidden in the background is the fact that there is little reward for working on curricular reform (as opposed to getting a grant). Instead, often, there is punishment. Taking large amounts of time away from research activity in publish-or-perish institutions can be suicidal for those without tenure and masochistic for all but the most established. At schools where teaching is emphasized, what counts is getting good student ratings. Educational experiments rarely enhance popularity because they cut off their most frequently used source of help: students who had the same course recently.

The essential question is what we are going to do about the existence of the computer. When departments of mathematics recognize that they must do something in this area as opposed to deciding whether some particular approach to teaching calculus is better than what they are doing now, we can begin to attack this serious problem. We need to look at our entire elementary curriculum and decide to what extent computers should be used in teaching. Reexamining how we teach calculus is at the heart of any such investigation. This will not be done easily or quickly, and we cannot wait for the technology to improve before getting involved if we want it to meet our needs. Many years of experimentation will be needed before there is any kind of agreement on how the new kind of calculus should be taught. I think we need to use the following sorts of guidelines.

(1) Mathematics departments must be regarded as laboratory science departments, and we need our own technicians for this purpose who will be able to help us in using computers or calculators efficiently. Before we can convince our administrations to increase our budgets accordingly, we have to convince ourselves. Grants may ease the burden, but are not a substitute for a permanent commitment to make intelligent use of computers in the mathematics curriculum.

(2) Those willing to experiment with using computers in their teaching must be rewarded in the same way that other kinds of research activity is rewarded, and expecting high student ratings in experimental courses is unfair and unproductive.

(3) Foundations should support workshops on how the use of software can augment the teaching of mathematics. Exacting promises in advance that some particular software will be used or exposing the participants to too many different kinds of software is counterproductive. It is not reasonable either to expect revolutionary changes in the way that calculus is taught to occur rapidly any more than one could expect research support to result in the rapid solution of problems that have been outstanding for many years. Getting the mathematical community to reexamine how a course is taught to hundreds of thousands of students each year is a big step forward. Expecting (as does the National Science Foundation) large scale calculus courses to be taught all over the country with substantial computer involvement just a decade after the first personal computers became available is foolish.

(4) Developers of computer-assisted teaching programs should temper their natural enthusiasm and provide teachers they are trying to persuade to use them with concrete information on what they must ask for from their administration to have a reasonable chance for success. The programs at Duke and Purdue Universities supply such information and demand that faculty embarking on the program undertake adequate training; few others do. Only those armed with this kind of information can ask for the kind of help essential for the success of a new program. Warning potential users of pitfalls may discourage some from trying, but avoids the bitterness that accompanies failure.

What I fear most is that this kind of highly needed educational reform will go the way of other programs that were overadvertised in the past. Even with the best of intentions and the efforts of highly capable and hard working mathematicians and educators, we can turn the public against us (as we did with the "New Mathematics") if we use too much hype. We have had only limited success with the teaching of calculus during my forty years as a teacher. I do believe that we will do a better job if we use the computer as we teach it, but the millennium will not arrive very quickly, and we may do ourselves in if we claim that it will.