Comment

Do the math

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It looks like the tenuous cease-fire is not going to hold. Already there are signs of renewed hostilities. Both sides are marshalling their forces, hurling derogatory slurs at one another, and preparing for open warfare. I am not referring to Darfur, or to the Middle East. I am talking about something much more intrinsically fraught with ominous possibilities. I am talking about the teaching of mathematics in American schools.

The average American student can do many things that his or her parents cannot dream of doing: program a video cassette recorder; get a high score in any video game; download almost anything, legally or illegally, to his or her iPod, and multitask to an extent that makes one wonder how many brains are really in there. But when it comes to doing math, that same student displays the approximate level of intelligence of a paramecium.

At least, that's what both national and international tests seem to show. American 8th grade students trailed those from Japan, South Korea, Singapore, Taiwan, Hong Kong, and many European countries in the recent Trends in International Mathematics and Science Study. In the state of Washington, this year only about half the 10th grade students passed the basic math proficiency part of the state education test. A website, http://www.nychold.com/, has been set up so that concerned parents can find links to information about battles over math education in their home states. A reading and math tutoring system focusing on basic skills that originated in Japan, Kumon, now has franchises in many states and a global clientele of more than 4 million children in 43 countries.

Perhaps in response to all this, in September of this year, the National Council of Teachers of Mathematics issued a report recommending that schools focus more on teaching basic math skills and stop trying to teach dozens of different mathematical topics in each grade. This is the same National Council that, in 1989, issued a report that said exactly the opposite, so you'll forgive me for viewing their current statement with the same degree of unease that I might greet, say, an announcement by President Bush that we were going to do the whole Iraq thing all over again but this time get it right.

That earlier report, and about ten years of experimentation in math education that preceded it, produced a curriculum that emphasized letting children find their own ways to solve math problems and use calculators to perform elementary operations. The movement had a number of names, including 'fuzzy' math and 'new' math, and it was imposed on an entire generation of students over, in many cases, the objections of their parents. California abandoned this idea a half dozen years ago, and the scores of California students on standardized tests went up sharply as a result, but math educators in many states have resisted the call to 'return to basics'. A *New York Times* article on November 14 quotes R James Milgram, a math professor at Stanford University, saying that "the math situation in the United States is a complete disaster."

The self-esteem movement, which hit the US school system at just about the same time 'fuzzy' math did, hasn't helped. By emphasizing that the student's own idea of how to attack a problem, or even the student's own answer, was good even if it was wrong because it was the product of the student's creativity, the drive to increase self-esteem fed perfectly into a system of mathematics instruction that focuses on the student's own approaches. The same *New York Times* article recounts the story of a Seattle mother who was aghast to find that her stellar 6th grade student had no idea how to do long division. When she confronted his teacher, she was told, "We don't teach long division. It stifles their creativity."

Personally, I think the best route to self-esteem is getting the right answer, and having confidence that you know how to get the right answer. And I think when it comes to getting the right answer, there is no substitute for being taught a reliable method. But I think there's more to our problems with math education than a well-intentioned, but muddle-headed, educational philosophy. I think our failure to train people properly in mathematics reflects our lack of appreciation for just how unusual a field it is.

There's something about mathematics. It isn't like any other subject. Most of us are familiar with the generalization that the average philosopher or social scientist tends to do his or her best work relatively late in life; biologists do it in their 40s and 50s; chemists in their 40s; physicists in their 30s and 40s; and mathematicians in their 20s to early 30s (there are, of course, many exceptions, though seemingly fewer for math than for the other subjects). But it isn't just that the best work is done very early in the case of mathematicians. It's that it's often their only important work, period. In every other subject I know of, even after the peak of one's career, the typical practitioner still can make significant contributions. And with age, even if one's mastery of the field may not increase much, it usually doesn't decline much either. But mathematicians often seem to regress relative to their field once they are past their prime. A number of them have told me that after their major work was completed, they knew it was time to devote themselves primarily to teaching others, because they simply wouldn't be able to do cutting-edge stuff any more.

The peculiar nature of mathematics is most apparent, I think, to a teacher of other subjects. I regularly teach freshman chemistry, a subject that most people in class don't want to be taking, and the distribution of backgrounds and abilities among my students is about as broad as it gets. But with very few exceptions, any of them can improve their understanding of the subject if they keep working at it. Progress can be frustratingly slow in some cases, but it's nearly always there. It was that way for me, too, when I was a student: some things were harder for me than others, and in some instances I didn't spend enough years working on them to experience that magical moment - I call it the pedagogical moment - when the learning curve turns sharply upward and everything suddenly starts to make intuitive sense. But I always felt like I was making at least some incremental progress when I put additional time and effort in.

Except in mathematics. I think that, unless you are one of the few who are going to be professional mathematicians or who have an intuitive grasp of the subject, when you study mathematics at some point you hit a wall. It's in a different place for each person (geometry for some, algebra for others, calculus for many), but once you hit it, there's almost no chance you will go past it. This wall makes it literally impossible to teach fundamental mathematical concepts to a broad collection of students. But that, of course, is exactly what the 'new' mathematics curriculum has been trying - and failing - to do, for over 20 years.

If I'm right about this, and I believe I am, then the 'new' math goal of having all students understand what they are doing rather than memorizing methods and regurgitating answers is simply unattainable. True, the old approach produced many people who disliked math as a subject and believed they couldn't understand it. But what if that belief was right? Mathematicians may wish that everybody understood and loved their subject, but it looks to me as though that desire is producing generations of students who can't use mathematics, and isn't being able to use it what the real objective ought to be, for most people? My mother disliked math and certainly didn't understand it in depth, but she was trained in doing it so well that she made her living as a bookkeeper for many years.

All this, of course, has enormous implications for biology in the age of genomics. Data gathering is useless without data analysis. Genomics has led to mountains of data, requiring increasingly sophisticated analysis, yet biology has always attracted scientists who wish to avoid the mathematics in physics and chemistry. Such biologists are at the mercy of those who claim to have extracted important insights from genomics data by complex analytical methods. The ranks of bioinformatics are largely drawn from people with a background in math or computer science; it seems to be easier for those scientists to learn some biology than it is for biologists to learn the other subjects. Once a high priesthood of the mathematically sophisticated is established, not only is there less incentive for the flock to learn the tools, there is actually a positive incentive for the clergy to keep such things as mysterious as possible. We end up believing that to analyze (or model) a system is to understand it. Not only is this untrue (you can model anything with enough variable parameters), it is stifling. We need biologists who can analyze data themselves, or at least critique the results of those who do.

Medical research creates an even greater demand for mathematical literacy, among both scientists and the scientific press. Not a week goes by without some study purporting to show that this food is bad for you or this activity protects you from that disease. And the following week, it is likely that some other study will purport to show exactly the opposite. No wonder the public is anxious, confused, and increasingly distrustful of science. Tragically, in many cases the fuss is over small differences in risk that are at the border of statistical significance. But when the researchers in question use p-values without really understanding what statistics should be applied to their data, when they bin things so as to produce an effect that they can publicize, and when most science reporters don't have the background to realize that the conclusions are questionable at best, the result is often much ado about nothing.

Yet statistics is the one branch of math that everybody should be able to grasp, because there is no need for a deep understanding of its foundations. Statistics can be taught - often is best taught, actually - as a simple set of tools that can be used to provide information about what sets of data mean, or don't mean. You can learn statistics without being able to derive a thing. It's eminently practical, not very sophisticated mathematically, and can be made fun. What a pity that, with the exception of some medical students, almost nobody is given any formal training in it apart from some half-hearted lectures as part of a lab course or two.

So here's a simple little proposal for reform in the educational system, starting at the elementary school level and leading right through graduate school. Students need to memorize basic math facts and learn simple algorithms that will allow them to do calculations - or at least estimate answers - without the aid of a calculator. I also think there should be an emphasis not only on the basics of math, but also on developing computational skills. There should be more numerical problems and fewer word problems, especially in high school. Every college science major should be required to pass a full semester course in statistics - no exceptions. And graduate students in biology need not only to have this background, but to show a familiarity with more sophisticated concepts such as hidden Markov models and network analysis. The best context in which to teach that material is a good elementary course in bioinformatics, which should be required of every life science doctoral candidate.

If we start to do this now, maybe we will produce a generation of young biologists who will actually be able to understand what genomic data mean. Maybe they will question the pronouncements of the modelers instead of accepting them blindly. Maybe they will challenge researchers who claim that behavior causing a 10% increase in risk of heart disease is something we should all worry about, when neither their sample size nor their margin of error justify paying any attention to it at all. And maybe they won't have to fight the math wars for the education of their children. Or if they do have to, maybe they will be equipped to win.