ON MATH AND SCIENCE EDUCATION IN THE UNITED STATES*

Remarks Delivered at The Johns Hopkins University

April 10, 1985

Iris C. Rotberg

National Science Foundation

When I last conducted research in the Johns Hopkins Psychology Department, I worked with Jim Deese in the area of Psycholinguistics. We looked for meaning in clusters of word associations. This afternoon, I will look for a different kind of meaning. I will try to make some sense out of the literally dozens of research reports that have been published in the past two years about the state of our education system -- particularly math and science education.

As you know, the conclusions of many of these reports are quite grim. (At least the large print. Bad news makes better press than good news.) One report concludes:

> Our nation is at risk. Our once unchallenged preeminence in commerce, industry, science and technological innovation is being overtaken by competitors throughout the world.

---

*This paper is a revised and updated version of an article entitled "A New Perspective on Math and Science Education," published in Phi Delta Kappan, June 1984, pp. 668-673. The views expressed are those of the author and do not necessarily reflect the positions or policies of the National Science Foundation.

Not all observers, however, have been quite so pessimistic. A. Bartlett Giamatti, President of Yale and a member of one of the most publicized recent education commissions, recently wrote that he considered making the following remarks to Yale's entering freshman class.

> Ladies and gentlemen of the class of 1987: I am delighted to see you all here. After all the critiques and debate about the American high school this summer, I did not know if anyone could or would show up this fall. You are a very strong group, as strong a freshman class as we have ever had. Your presence here argues for the health of American secondary education...you have come here not despite but because of school systems and teachers who have taken a battering recently, a battering all out of proportion to their responsibility....

Today I will discuss several conclusions from recent reports in the area of math and science education and assess the extent to which they are supported by research findings. The most common conclusions are:

1. The U.S. system of education is not producing trained scientists, mathematicians, engineers, and computer scientists in numbers sufficient to meet economic and military needs.

2. The problems will become even more severe in the next decade, when technological advances will increase the need for highly trained personnel in these fields.

3. U.S. students are less well trained, as measured by their test scores, than are their peers in other industrialized countries.

4. U.S. students today are less well trained than were their predecessors.

I will discuss here (1) the extent to which these conclusions are supported by research findings; and (2) the tradeoffs in curriculum, school finance, and social opportunity that should be considered before implementing solutions to these perceived problems.

Research Findings

The first contention is that the American system of education is not producing enough scientists, mathematicians, engineers, or computer specialists to meet demands.

Recent findings of the Bureau of Labor Statistics (BLS) show that the facts are quite different. Not only are there enough scientists and mathematicians, but by 1990, the number of science and math graduates at all degree levels is expected to exceed the number of jobs in these fields.

Projections also show an overall balance between supply and demand for engineers for the rest of the decade. The shortage of engineers that has received so much public attention in the past few years has been limited to a few specialties -- electronics, computer design, and aeronautical engineering -- and certainly does not justify massive efforts to change basic curricula. There may be a shortage of engineers with doctorates who are willing to join university faculties. But this shortage is caused not by any inadequacies of the education system but simply by a lack of financial incentive for young engineers, who are well-paid by industry, to accept lower-paid university positions. The BLS sums it up this way:

> During the 1980's, the United States will be turning out about twice as many bachelor's degree graduates in engineering as in the 1960's, a decade of rapid economic growth, high defense spending, and a space program that put an astronaut on the moon.

The fact is that we will not need more engineers than we are now turning out.

While the current demand for computer scientists exceeds the supply, the number of students receiving computer science degrees is rapidly increasing. By the end of the 1980's, supply-demand imbalances may be largely corrected.

In general, labor market projections show that the education system is in fact producing adequate numbers of scientists, mathematicians, and engineers. Shortages that do exist (primarily in computer fields) are likely to be reduced in the next several years, and there will be surpluses in many fields.

The BLS suggests that some of the exaggerated predictions of shortages stem from the methodology used in surveying the projected business and military demand. Corporations typically overestimate both overall industrial growth and their share of the market. Each defense industry apparently assumes that it will receive a disproportionate share of the contracts it bids on. This multiplies the overall requirements of the industry many times, because only one award will actually be made. The result is a large overestimate of the need for technical staff. Other evidence suggests that corporations report shortages of highly trained personnel when they cannot attract the best graduates at the salaries they would prefer to pay. Under such circumstances, managers too quickly conclude -- almost as a defensive gesture -- that the fault lies in a shortage of qualified applicants.

. . .

The second major contention of recent reports is that technological advances will increase future demand for highly trained and computer literate personnel.

No one can predict with certainty what these advances or their effects will be. Projections suggest that some computer and engineering fields will be among the <u>fastest-growing</u> occupations. But contrary to popular belief, the greatest <u>number</u> of new jobs will not be created in these fields. Most new jobs will be in low-skilled occupations that require quite low levels of scientific and mathematical knowledge.

This projection is consistent with the findings of a recent study of college graduates in the mid-Seventies, which showed that almost half were employed in jobs that did not require college training. These graduates were doing jobs in which at least 70% of their colleagues doing the same job had not attended college.

The fact is that not one of the 19 occupations expected to produce the largest numbers of new jobs between 1982 and 1995 will be in high technology. Some comparisons are helpful.

The Bureau of Labor Statistics projects:

779,000 new openings for building custodians
744,000 new openings for cashiers
719,000 new openings for secretaries
696,000 new openings for office clerks

compared to:

217,000 new openings for computer systems analysts
205,000 new openings for computer programmers
584,000 new openings for engineers
418,000 new openings for engineering and science technicians

Probably more surprising is the prediction that the number of new kindergarten and elementary teaching positions (511,000) may be greater than the number of positions for computer systems analysts and for computer programmers combined (422,000). And the number of new openings for engineers (584,000) will not be substantially greater than the 511,000 new openings projected for kindergarten and elementary teachers.

It is interesting to compare these figures with the occupational choices of the 1984 freshman class. 16.5% of these students said they planned to become engineers or computer specialists compared to only 3.4% who planned to become elementary school teachers. Interest in computer fields among college-bound seniors taking the SAT increased almost tenfold between 1973 and 1983.

I do not mean to suggest by this evidence that our society will not need significant numbers of highly trained scientists, engineers, and computer specialists. We clearly need such specialists. However, reports of shortages, poor training, and the proportion of total employment accounted for by these fields have been greatly exaggerated.

. . .

A third contention of recent reports is that American students are less well trained in science and mathematics -- as measured by their achievement scores -- than are students in other industrialized countries.

Yes and no.

It is true that the average high school student in the United States scores lower in international comparisons than the averagehigh school student in other industrialized countries.

But these results do not compare equal proportions of high school age groups. In Europe, academic schooling for those between ages 16 and 18 does not attempt to serve virtually the entire age group. In fact, when these studies were conducted (late 1960's and early 1970's) only about 20% of the age group in Europe attended upper-secondary school -- the highest-achieving 20% -- compared to 80% of the age group in the United States.

As a result, international studies of achievement often compare the average score of more than three-fourths of the age group in the U.S. with the average score of the top 9% in West Germany, the top 13% in the Netherlands, or only the top 45% in Sweden.

When the top students are compared, American students score at about the same level in mathematics as their counterparts in many industrialized countries -- though they still score lower than their peers in Sweden, Japan and Israel.

Top U.S. students also score at about the same levels in science as students in other industrialized countries -- better than students in France, Belgium, and Italy; not as well as students in New Zealand, England, and Australia.

Preliminary results from a more recent international study of mathematics achievement, conducted in the early 1980's, are consistent with the earlier study. Overall, American 12th grade students performed well below the average student in the final year of secondary school mathematics in the other countries. But American students in calculus classes (who are likely to be more similar to the comparison groups in other countries) performed at or near the international median in almost all content areas. The more recent study also compared mathematics achievement for students in eighth grade -- a grade where students in the U.S. and other countries are more likely to be comparable -- and found that the American students performed at about the international median in algebra, arithmetic, and statistics. In geometry and measurement, the American students performed at about the 25th percentile. Not an impressive finding, but certainly a more realistic picture of American mathematics education than the widely reported findings for 12th graders which show American students well below the international median in _all_ areas of mathematics -- a finding based on the fact that the _average_ American student is being compared with top students in the other countries.

I could go on, but it is sufficient to note that, when equal proportions of age groups are compared, the results do not reflect as badly on the American system of education as the reports would lead us to believe. This is especially true in light of the fact that U.S. schools not only provide an education for the brightest students but, unlike their counterparts abroad, must do so in a school environment that includes virtually the entire age group, often working together in the same classroom.

It also might be reassuring for critics of American education to know that the Japanese -- despite their extremely high scores on math tests -- are reexamining their own education system. Their concern appears to be the opposite of that expressed by recent critics of American education. They fear that their education system, by emphasizing memorization and high achievement scores, produces a population that is strong in basic educational skills -- as one Japanese observer put it, "the best in the world for settling problems assigned to them," but that it may be falling behind the West in terms of creativity. "I think there is room for us to improve Japanese education," he says -- a conclusion which may surprise some critics of American education.

. . .

The fourth major point made by recent reports is that American students today are less well trained in math and science than were students in previous years.

I doubt it.

The fact is that high school students took more mathematics in 1980 than they did in 1972 and about the same amount of science. Among college-bound students who took the SAT, the amount of academic coursework has <u>increased</u> over the past seven years, with the largest increases occurring in mathematics and the physical sciences. There also has been greater enrollment in advanced, accelerated, and honors courses.

The achievement test scores of students who are likely to major in science or mathematics have remained high in these areas. Declines are more evident in tests that assess the basic scientific and mathematical knowledge of the general population.

It may be useful to review recent test score findings to illustrate these points. Scores on College Board science achievement tests in biology, physics, and chemistry, taken by the top students among the college-bound population, are as high or higher than they were in the early 1970's. The same is true of mathematics achievement test scores. In addition, scores on College Board Advanced Placement tests in science and mathematics were at least as high in 1983 as they were in 1973, despite increased numbers of students taking the tests. Achievement test scores on the Graduate Record Examination (GRE) show mixed results over the past nine years. Mathematics scores have gone up; physics scores have gone down; engineering scores have remained steady. Recent international assessments show modest test score gains between 1964 and 1982 for 12th graders taking college preparatory mathematics. All of this suggests that in general our top students do as well or better in math and science than they did in previous years.

The widely reported declines in test scores are based on tests administered to a broad cross section of the population. Even here results are mixed. The National Assessment of Educational Progress (NAEP), which assesses representative samples of elementary and secondary students, shows that 9-year-olds have scored at about the same level in science since the 1972-73 science assessment, while scores for 13- and 17-year-olds have declined. The recent international study shows that 5th and 9th grade science scores improved between 1970 and 1983, with students in 1983 better able to deal with process skills (a finding which NSF staff hopes has something to do with the NSF science curricula stressing these skills). During roughly the same period, mathematics scores on the NAEP assessment have stayed about the same for 9-year-olds, improved for 13-year-olds, and declined for 17-year-olds. The international study shows a modest decline in 8th grade mathematics achievement. Clearly, results even for the general student body in elementary and secondary school are mixed.

They also are mixed when one looks at test scores for the general college population. The scores of college-bound students on the American College Testing (ACT) Program natural science examination (a broader cross section of students than those who take the College Board achievement tests) have remained approximately the same since the mid-1970's. Mathematics scores for college-bound students on both the ACT exam and the Scholastic Aptitude Test (SAT) declined from the late 1960's to the mid-1970's, when they began to level off. ACT math scores show some evidence of continuing decline, while SAT math scores have remained essentially the same for the past ten years. (The average score was 472 in 1975 and 471 in 1984). The widely reported decline in the proportion of high SAT math scores also has been exaggerated. In 1972, 17.8% of college-bound seniors scored at 600 and above, compared to 16.6% in 1984. The percentages for 700 and above were 3.5% and 3.3% respectively and for 750 and above, 0.9% and 0.7%. Finally, scores of graduate school applicants on the quantitative portion of the GRE are higher now than they were in the early 1970's.

The declines that do occur are explained in part by increases in the numbers, and changes in the socioeconomic characteristics, of students taking the test. The ACT Program notes that "small changes in average scores can result from a variety of factors, the most notable being changes in the demographic characteristics of the students taking the tests." An advisory panel on SAT scores, reporting in 1976, noted that as much as three-fourths of the decline in scores between 1963 and 1970 can be attributed to changes in the numbers and socioeconomic characteristics of students taking the test, and one-fourth of the decline after 1970 can be accounted for by continuing demographic shifts. Other changes noted by the panel are curriculum changes, television, and changes in family structure. The panel may have underestimated the role of population changes which became more visible after the panel reported in 1976. (One observer, not a member of the panel, attributed that score decline to increased strontium-90 in the atmosphere.) In any case, these declines have little to do with the quality of education, and changes in test scores that can be attributed to population changes -- or even to strontium-90 -- are certainly unreliable measures of the quality of education.

Implications

Why does all this matter? Does it make a difference if we overstate or inadequately define the problems in math and science education? I have several concerns about educational "reforms" based on recent rhetoric, though clearly there may be some benefits, for example, more training opportunities for teachers and greater public acceptance of increasing educational expenditures when these increases are linked to reform.

For the most part, however, I do not believe that these reforms (though intentions may be good) will produce fundamental improvements in the quality of education children receive. Not surprisingly, the reforms selected are those which appear to be the most straightforward to carry out. It is simpler to increase the number of required courses than to improve the quality of what is taught. It is less demanding to install computers in classrooms than to teach children how to think logically. And it takes less thought to give awards to a few teachers than to improve working conditions for the teaching profession as a whole.

There is increasing evidence that recent reforms -- many, I believe, not based on a careful analysis of the problem -- will be irrelevant to the more important issues in math and science education and that some may produce negative, though unintended, consequences which will make it even more difficult for schools to provide a high quality education. Some examples may be useful.

First, reforms stress increasing requirements, so that all students must take more algebra, physics, or chemistry. These reforms are based on the assumption -- quite unsupported by research -- that the U.S. educational system is not producing adequate number of highly qualified scientists, engineers, mathematicians, and computer specialists. However, the problem is quite different: the population in general is not well-informed about basic scientific issues or about how to perform simple mathematical applications, such as problem solving. The problem is not the number or quality of those trained to be scientists. The emphasis of the reforms on increasing requirements for traditional science and math courses (and on mandated test programs which encourage coursework that can be measured by objective test items) does little to improve the education of the large majority of students who might benefit more from curricula that are not designed along narrow disciplinary lines. As we all remember from our own experience or that of our children, most students learn these traditional math and science courses by rote. It is unlikely that simply requiring more of these courses will increase the average student's knowledge about scientific methodology, scientific issues in the context of public policy, or about how to apply mathematics -- but this is where the emphasis is needed.

Unfortunately, these trends to simply require more courses seem inconsistent with some of the more useful science curricula of the past 20 years which have attempted to give students a chance to understand the development of a limited number of major scientific concepts -- but to understand these concepts in depth -- rather than attempting to teach a lot of superficial facts in survey courses which are quickly forgotten. (Like Federal budgets, it is easier to add to science textbooks than to make policy decisions about what to cut.) One observer put it this way: "Requiring courses does not guarantee learning in courses." Another noted that "forcing students to take the same chemistry or algebra II they have been avoiding for the last 20 years is no answer." The French essayist Montaigne, in 1580, best reflects my concern.

> But as the steps that we take walking in a gallery may tire us less than if they were taken as a fixed journey, so our lessons, occurring as if it were accidentally, without being bound to time or place, and mingling with all our other actions, will glide past unnoticed.

In addition to problems in course content, increasing course and graduation requirements is likely to increase problems in another widely publicized area -- shortages of math and science teachers. In fact, the whole issue of teacher shortages needs clarification. The public debate (and proposed remedies such as extra pay or loan forgiveness programs) rarely mentions, for example, that there also are shortages in vocational/technical fields and special education.

And it fails to note that reported teacher shortages result not only from the simple unavailability of "qualified" math and science teachers, which is very real in certain parts of the country, but also from budget constraints and from surpluses of teachers in other fields. For example, out-of-field teaching, which is used as one measure of teacher shortages, often reflects the placement of surplus teachers of other subjects who cannot be laid off because of their seniority. As a result, this measure may be used to describe shortages in algebra teachers merely because history teachers are being asked to teach algebra -- not because there necessarily is a shortage of algebra teachers, but because the history teachers have seniority and cannot be laid off. Further, many school systems are likely to respond to increased math and science requirements by increasing out-of-field teaching, thereby reducing the quality of education in these fields -- exactly the opposite of what is hoped for in the reforms. And it is often the lowest achieving students who get the least qualified teachers.

And shortages of math and science teachers do not necessarily mean that these teachers can readily find jobs. For example, the State of Kentucky offered financial incentives for persons to enter teacher training programs in mathematics and science and then found that few available teaching positions existed for the first graduates. And in April 1983 -- the month in which the National Commission on Excellence in Education released its report, noting "particularly severe" shortages of math and science teachers -- the Chicago press reported that the Chicago Board of Education had made substantial reductions in the number of math and science teachers during the past several years. Indeed, Chicago had a surplus of math and science teachers. Many of these teachers were working as substitutes and not necessarily in their fields of expertise. More often than not, such problems arise as a result of financial strain on States and school districts. It is not so much that the teachers aren't needed as that the districts can't afford to hire them.

In addition to problems of teacher shortages, the enormous increases in bureaucratic requirements accompanying recent reforms also are likely to affect the quality of education students receive. These are increases in State requirements which make Federal regulations (about which there has been so much concern in recent years) seem mild. There literally are thousands of new laws and policies. It is estimated that Colorado alone has 114 new laws affecting public schools. And one observer has referred to California's latest reform bill as a "garbage can" -- a collection of everyone's bright ideas about what education should be like. It appears that State legislatures have moved from administrative and finance policies to direct control of curriculum and testing; noneducators seem to be making decisions about teaching principles and other instructional issues, while educators are spending their time worrying about money.

All of this means that schools are likely to become even more boring places, less intellectually stimulating for students -- and for teachers as well -- than they are now, certainly not a trend that will make it easier to attract outstanding teachers and principals -- without whom, of course, the education reforms can accomplish little. As a result of new requirements, teachers will have little discretion to make decisions about instruction and curriculum. Apart from autonomy, the sheer abundance of administrative work will mean less time for students. Unfortunately, these trends seem to run counter to the school effectiveness and management literature which emphasizes the importance of employees having at least the perception of some control over their own working environments. One observer summed it up this way, "Large size, bureaucratization, and fragmentation run counter to attempts to educate individuals . At the core of any genuine effort to provide education is the interaction between teacher and pupil."

I also am concerned that an overstatement of the problems in math and science education may reduce resources for other parts of the curriculum (a point which I fear may be of less concern to this particular audience than to some other departments at Johns Hopkins). However, other parts of the curriculum are in need of improvement at least as much as math and science. SAT scores, for example, have shown greater declines in verbal than in math scores. The quality of students' writing leaves much to be desired. A number of engineering schools are now revising their curricula to include broader liberal arts courses. Recent surveys of academic officials found that the humanities are losing many of the highest-achieving students to the sciences and engineering. Students are interested in careers, like computer science and engineering, which require no graduate training and will pay off. And students don't know a lot about history or government -- a point that is well illustrated by some quotations by Benjamin Stein based on his conversations with high school and college students in the Los Angeles area. I think these quotations might put the "problem" we face in some perspective.

> Recently a 19-year-old junior at the University of Southern California sat with me while I watched "Guadalcanal Diary" on TV. It goes without saying that the child had never heard of Guadalcanal. More surprisingly, she did not know who the United States was fighting against in the Pacific. ("The Germans?") She was genuinely shocked to learn that...the United States had fought a war against the Japanese. ("Who won?")
>
> (A) student (at the University of Southern California) did not have any clear idea when World War II was fought. She believed it was some time in this century.... She also had no clear notion of what had begun the war for the United States. ("Pearl Harbor? Was that when the United States dropped the atom bomb on Hiroshima?") Even more astounding, she was not sure which side Russia was on and whether Germany was on our side or against us....
>
> A few (students) have known how many U.S. senators California has, but none has known how many Nevada or Oregon has. ("Really? Even though they're so small?")...
>
> Of the teenagers with whom I work, none had even heard of Vladimir Ilyich Lenin. Only one could identify Joseph Stalin. (My favorite answer -- "He was President just before Roosevelt.")...
>
> None (of the students) could name even one of the first 10 Amendments to the Constitution or connect them with the Bill of Rights....
>
> Only a few could articulate in any way at all why life in a free country is different from life in an un-free country....

I also am concerned that inaccurate assumptions about the state of math and science education in the United States may lead to unrealistic expectations about the job market. Clearly, our society will need significant numbers of highly trained scientists, mathematicians, engineers, and computer scientists. But recent reports may already have led to unrealistic expectations on the part of some students, who are choosing these fields in large numbers.

The computer field provides a useful illustration. It is a field where the job market is still very good -- in fact where there still are problems on the supply side -- and where applicants with the proper training and experience can write their own ticket. But even in the computer field, jobs for some applicants are not so easy to obtain as they were a few years ago. The Bureau of Labor Statistics, for example, receives complaints from people who cannot understand why they are having difficulty finding a job when the news media and employment counsellors say there is great demand for computer programmers. The Los Angeles Times recently reported that the availability of computer jobs for high school students in the Los Angeles area has been greatly exaggerated yet the demand for computer training is overwhelming at the high school level. The New York Times writes that some colleges report that while two years ago their computer-science graduates were immediately hired as programmers, many are now starting as computer operators, a job that requires almost no professional training. Some employers tell applicants without experience not even to stop at job fairs. What are the reasons for these reports?

First, enrollments in computer training programs of all types -- high school, training institutes, colleges -- have risen sharply in the past few years -- although interest in computer fields for college-bound seniors taking the SAT in 1984 did decline for the first time in ten years and the proportion of the 1984 freshman class planning to become computer specialists was lower in 1984 than in 1983, but still a substantial number of students.

Another reason it may be more difficult for some applicants to find jobs is that as packaged programs become more widespread, employers have less need for programmers who know only how to code instructions.

There still continues to be a strong demand for qualified computer specialists. Both computer programmer and systems analyst positions will continue to be among the most rapidly growing positions in the economy. But employers are becoming more selective. The education requirements are increasing as are the requirements for training and experience in the field to which the computer is being applied. Systems analysts need a combination of skills, including a knowledge of areas for which they are designing systems. Programmers need more advanced skills than those that were readily marketable a few years ago. The expanding job market for new programmers is in new languages that will link different computer systems.

All of this is a relatively complex picture. I am concerned that it is not reaching students who hope that one or two programming courses will give them access to jobs in computer science. The field continues to have increasing opportunities, but these opportunities may not exist for students who do not carefully match their training and experience with the jobs they wish to obtain. This probably was not the case even a few years ago.

Finally, in reviewing implications of recent reports, I am concerned that little attention has been paid to the financial and social costs of recommendations and the tradeoffs that would be required. Money spent on a minor problem often uses resources that might better be spent on other, more pressing requirements. Similarly, reforms that do not consider implications for all parts of the society are likely to raise more problems than they solve.

It has been estimated that the total cost of all of the recommendations in recent reports would be $20 billion to $30 billion in new funds each year -- more than the total Federal expenditure ($15.4 billion) in FY 1983 for elementary, secondary and higher education programs, including student aid at the college level.

There also is little consideration given to the social costs of such recommendations as stricter course and graduation requirements. How does increased prescriptiveness of State requirements affect the ability of teachers to meet the individual needs of students in their classrooms, not a hypothetical student discussed by recent reports? And how would requiring algebra II or physics affect dropout rates, tracking, or the future employment prospects of students who fail? Bill Aldridge, executive director of the National Science Teachers Association, put it this way:

> High school science and math courses present content that largely duplicates content offered in college courses. These high school courses offer little more than preparation for that next course which the vast majority of students will never take. Present pro-

posals to increase graduation requirements in science and math will force all students either to take these courses or drop out of school.

Unfortunately, the conclusions of recent education reports have not encouraged a careful consideration of the effects of suggested "reforms." I am concerned that in the rush to offer solutions for ill-defined problems, we may neglect students and issues most in need of attention.

Thank you.