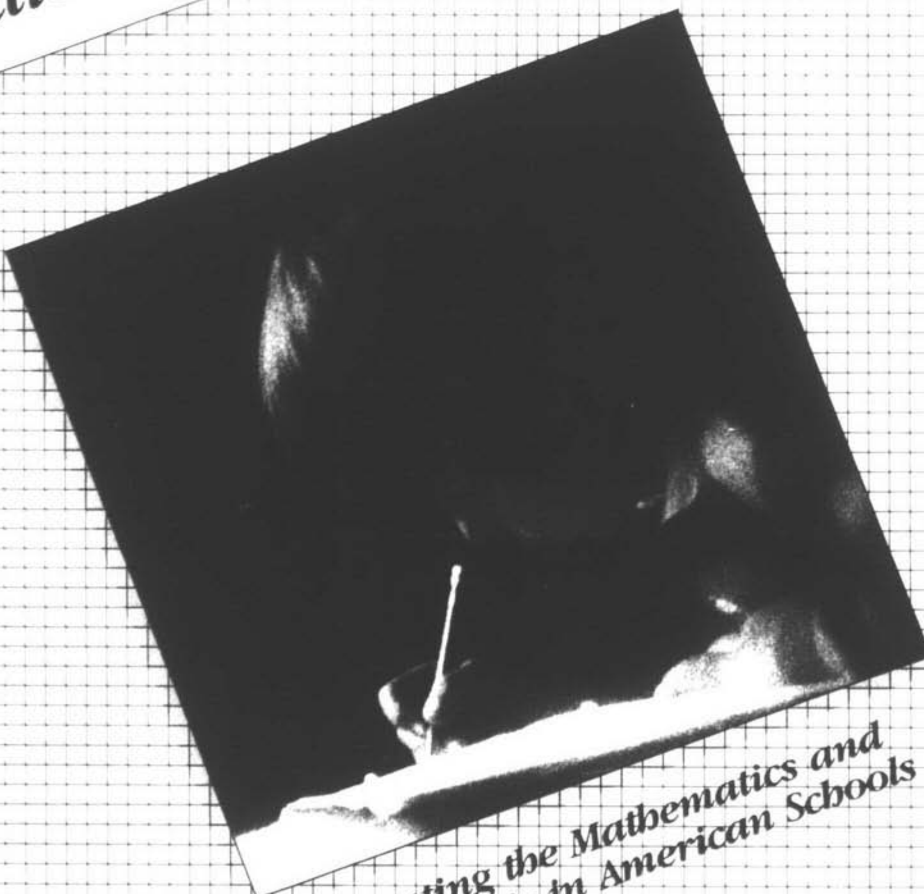
Education and National Survival:



Confronting the Mathematics and Science Crisis in American Schools

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The United States is now facing one of the sternest challenges in its history. Its current poor standing in international comparisons of school mathematics and science achievement has been as paradoxical as it has been painful. On the one hand, the U.S. is still acknowledged to be the world leader in science and technology. It is a nation whose scientific elite for the past 50 years has been in the forefront of research and discovery, a country whose major universities and training programs are the envy of the world and a magnet for students, scholars, and scientists from other continents. America's economic power has converted scientific and technological breakthroughs into top-quality, mass-produced consumer goods and services; its medical achievements have made possible superb health care and offered a model for other countries. The U.S. has also developed a system of civic education that is among the very finest in the world. Nevertheless, American public school education, especially in the areas of science and mathematics, is in dangerous conditon.

Over the past two decades many industrialized nations, such as Japan and the countries of Western Europe, and even emerging nations such as Korea and Taiwan, have recorded outstanding achievements in the education of the general population. Since 1966, the communist-bloc countries have launched an educational mobilization, adopting general education standards and technical training programs of unmatched quality and magnitude. During this same period, the overall achievement levels of American secondary school graduates have not only failed to rise, but actually plummeted. The same downward trend can be seen in literacy and basic skills, where levels which may have been sufficient for survival years ago are totally inadequate in today's world. The well-written but unfortunately understated report of the National Commission on Excellence in Education has provided the latest chapter of documentation for the decline of American schools.

In brief, the educational level of the American citizenry is already having a terribly damaging effect on our productivity and general economy. Furthermore, no matter how much we invest in military technology, educational decline will continue to undermine our national defense.

The many possible solutions to our current problems focus on improved teacher training, a complete redesign of curricula, and a solid, long-term commitment to change efforts.

It is ironic that our school systems are now producing graduates who, in the majority, are intellectually remote from the great American accomplishments in space exploration, nuclear power, computers, and other technological wonders of the 20th century. Today most Americans lack the science training to understand the essence of these achievements, and few can share in the excitement of scientific discovery on any level.

The Educational Crisis

A careful examination of our current educational programs in the light of anticipated educational, economic, and defense needs will enable us to determine what changes must be made in our schooling. The seriousness of our educational crisis was first made clear by comparative studies of American and Soviet mathematics and science education programs. It may therefore be appropriate to review a few of these striking comparisons to illustrate the real enormity of our predicament.

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The current secondary school graduation rate in the Soviet Union is 98 percent, in Japan 95 percent, and in the U.S. only 72 percent. Even more telling than these general statistics are comparisons of programs and enrollments in specific subject areas.

- Of some four million American students who reach the age of 17 each year, at least 70 percent have been taught arithmetic for nine years. Nine years of repetitious drill result in feelings of boredom and incapacity for the students, who usually emerge from a demoralizing arithmetic experience without the inclination or the ability to pursue either secondary school algebra and geometry or technical/vocational training. In almost all other industrialized countries, children complete arithmetic in six years; in the USSR, arithmetic combined with intuitive geometry is taught in five years.
- Only half of our students take as much as one year of plane geometry. Most of these never learn geometry because we attempt to teach it in a single year, while empirical evidence and modern educational psychology tell us emphatically that we cannot. Furthermore, our high school students are not being taught solid geometry. Therefore, they rarely have the workable perception of three-dimensional space that is essential to many areas of science, technical design, and engineering. In contrast, all Soviet students study geometry continuously over a ten-year span: five years of intuitive geometry (at least one hour per week in grades one through five), three of semi-rigorous plane geometry (two hours per week), and two of solid geometry (two hours per week).
- While the great majority of Americans are struggling with nine years of arithmetic, Soviet students are working

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through a challenging and comprehensive compulsory mathematics curriculum that comprises six hours per week in grades one through eight and five hours in grades nine and ten (a total of nearly 2,000 class hours over ten years). In this ten-year period the Soviet program covers the equivalent of at least 13 years of American schooling in mathematics, and does so much more thoroughly and effectively, culminating in a calculus course taught in grades nine and ten.

• American secondary school physics, another building block of science education and technical training, is in extremely poor condition and must be changed radically. Less than a sixth (16 percent) of our high school students take even a one-year course in this discipline, while in the USSR all secondary school students take a compulsory five-year sequence of physics courses. The total number of physics teachers for some 16,000 U.S. school districts is less than 10,000 and shrinking rapidly. The total number of physics teachers in Soviet general education day schools alone is 123,000, and the USSR trains another 8,500 specialized physics teachers every year.

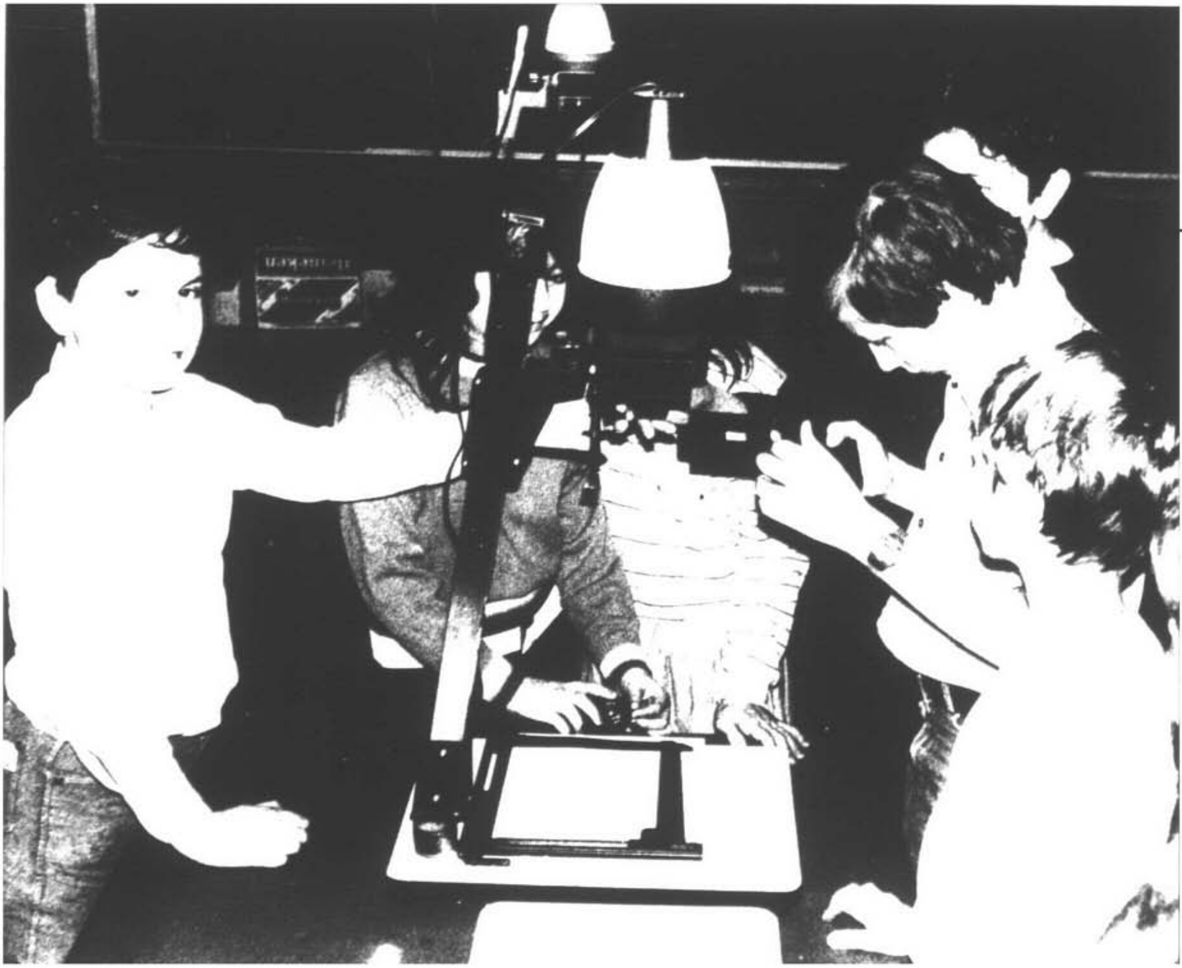
• The pattern continues in other subjects. In chemistry, only a third (35 percent) of our high school students take a one-year course, while all Soviet students complete four years of chemistry, including a full year of organic chemistry. Soviet students also receive six years of compulsory training in biology (compared to the one-year biology course in the United States), one year of astronomy, three years of mechanical drawing, and ten years of workshop and technical training.

• Our educational crisis is by no means limited to mathematics and the sciences. Only 16 percent of our students receive any exposure to geography as a separate subject, mostly in the form of a one-semester course. Geography training has all but disappeared. In the Soviet Union, on the other hand, all students take a five-year sequence of courses in the physical, economic, and political geography of the USSR and the world. The total number of geography teachers in the Soviet general education day schools is 98,000, and 6,000 specialized geography teachers are being trained every year.

• All Soviet children are obliged to take seven years of a foreign language, while fewer than 18 percent of U.S. public high school students study any foreign language, and fewer than 4 percent receive more than two years of foreign language study.

• Soviet training programs for skilled workers and white-collar technicians are based on a general secondary education which includes mathematics, physics, chemistry, geography, economics, international relations, history, and foreign languages and corresponds to at least 13 to 14 years of the best American schooling, achieved by only a small fraction of our own young people.

The vast majority of our high school graduates have not studied physics, chemistry, geography, or a foreign language, and have had only a modicum of mathematics. Not only do they lack a solid foundation for further training; they cannot even apply basic mathematics and science to simple jobs. This results in a personal tragedy of shattered hopes for countless young Americans. It is also a national tragedy, for it diminishes America's overall position in the world and places a tremendous burden on the economy and society, which must bear the staggering costs of unemployment; on industry, which must invest huge sums even for narrow, short-



term training; and on institutions of higher learning, which must provide costly remedial courses.

Some Aspects of the Present Crisis

The condition of American education is an extremely complex but sensitive issue that demands objective and thorough analysis and sober assessment. If we are to root out the sources of our current crisis, our perceptions must not be blurred by wishful thinking, paranoia, or any other predisposition to commend or criticize. With this in mind, let us take a brief look at three areas in which foreign efforts may suggest possible new approaches to the educational crisis in the United States.

Teachers. A country's educational system is a reflection of the entire society in all its complexity—its history, its culture, its aspirations and values. Ours is now producing alarmingly low numbers of competent teachers, particularly in mathematics and the sciences. Noncompetitive salaries and stressful working conditions are largely to blame. But the root of the problem has been widespread public indifference to the quality and status of teachers in the U.S. These circumstances cannot help but have a pernicious effect on all aspects of schooling.

Most of the students now entering schools of education—that is, candidates for teaching positions—rank in the lowest fifth of high school students taking the Scholastic Aptitude Test. Furthermore, possibly as a holdover from the days of the one-room schoolhouse, American elementary school teachers, many of whom have no specialized training, are expected to teach mathematics. This is unfair to the teachers and often very damaging to the children. When the elementary school teacher corps is so poorly treated, poorly trained, and poorly deployed, it is no wonder that their students early on develop negative attitudes, particularly toward mathematics and the sciences.

What has helped to make the remarkable achievements of Soviet mathematics education possible is that, from the fourth grade on, the subject is taught by a specialized mathematics teacher whose training is equivalent to at least a master's degree program in mathematics in the United States. Even elementary school teachers (grades one through three) receive extensive training in mathematics, the sciences, and educational psychology and teaching methodology based on advanced research. The same applies to the teaching of science and other subjects from the fourth grade on.

Educational Psychology and Curriculum Design. The steady decline of American school mathematics education has brought calls for new teacher training, new curricula and materials, and new "technological" instructional media. For reforms to have a lasting impact, however, they must be based on a genuine understanding of the nature and development of the conceptual and cognitive processes involved in learning mathematics.

The Soviet Union has made tremendous efforts over the past 40 years to study the psychological aspects of mathematics learning. This has resulted in a large body of outstanding research and unexcelled levels of mathematics achievement for the general population. Focuses of Soviet research include principles of mathematical conceptualization, problem solving, logical reasoning, programmed instruction, spatial perception, and methods of discerning and developing mathematical abilities.

The Soviet school mathematics curriculum has been designed, developed, revised, and tested over more than a decade with the participation of teams of world-renowned research mathematicians, leading mathematics educators, outstanding teachers, and specialists in the psychology of learning and teaching mathematics.

The Soviets have also proven adept at exploiting foreign educational research. In 1959 a French periodical printed a paper by Pieter van Hiele entitled "La pensée de l'enfant et la géometrie" ("Children's Thinking and Geometry"), one of the most important breakthroughs in the psychology of learning and teaching geometry. Pieter and Dina van Hiele-Geldof, together with their professor, the famous Dutch mathematician and educator Hans Freudenthal, introduced the idea of five levels of psychological development in geometry. The paper went virtually unnoticed in both Western Europe and the United States. I was fortunate, however, to learn from Russian monographs of the van Hiele paper and of significant research and experimentation done by the Soviets on the van Hiele-Freudenthal theory. The Russians had not only verified and refined the van Hieles' work, but had subsequently adopted this theory as a foundation of their new geometry curriculum and their innovations in the methodology of teaching geometry.

Since American students who take the one-year school course generally have no prior knowledge of geometry and are at van Hiele's first psychological level of development, they cannot be expected to master material from the fourth development level.

As for high school science, many of the individual programs and textbooks for the American one-year physics and chemistry courses that resulted from the post-Sputnik national curriculum reforms are quite modern and comprehensive. Some of them have served a valuable function in training a new corps of outstanding scientists from among our academically superior students. Yet these "packaged" one-year courses are, like our geometry course, written at the highest developmental level, with little regard for the students' learning processes. For the general population, these courses are simply too intensive and thus totally inappropriate. This is one of the main reasons why enrollments in physics and chemistry are so low.

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In the Soviet compulsory five-year physics sequence, the student is first offered two years of intuitive, descriptive, and experimental physics two hours per week; then he or she is exposed to physics for three years (three, four, and five hours per week, respectively) at increasingly higher levels of sophistication and rigor. Soviet research in the psychology of learning and teaching mathematics and science has been aimed particularly at achieving this kind of level-by-level mastery. The "packaged" one-year course in physics (attempted only in the U.S.) should be replaced by a multi-year sequence (two to three class hours per week). The same

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applies to our one-year chemistry course.

Commitment. Some commentators have remarked on the failure of efforts to make lasting improvements in education in the period after Sputnik. If one examines the facts, these efforts have had only limited effect for two reasons above all: these reforms were geared to the more able student, and the impulse was not sustained, perhaps because of the naive hope that a short-range or one-shot effort could solve deep-seated long-term problems. This is in sharp contrast to Soviet or Japanese programs developed over a period of decades.

It takes 20 years to produce a qualified scientist or engineer, of which the first 10 to 12 years of training are crucial. If our public schools cannot attract and hold students to the sciences, a generation of future scientists will be lost forever. Yet, as the standard measures of academic performance show, our educational system is producing fewer and fewer able students in all fields.

Recommendations

The challenge to the U.S. is formidable. Resolving our educational crisis will be an undertaking of unprecedented magnitude. This will mean raising the nation's general level of educational achievement by some three to four years—equivalent to the level already achieved by the Japanese. It will require a sustained effort by all segments of our society, private and public investment, and, above all, imaginative and engaged leadership at all levels of government. Our goal should not be to imitate foreign methods or systems but to conceive whatever new forms of American education are necessary for the continuing growth of our country and its people.

I would make the following recommendations for curricular reforms and long-term structural changes:

- Develop a completely new mathematics program for all children, covering all of arithmetic in the first six years of school. Intuitive geometry should be an integral part of the new program from the first grade on. Introduce algebraic thinking in the last two years of this six-year program.

- Offer all students in grades seven–nine a new three-year sequence in algebra and a separate, parallel three-year sequence in semi-rigorous geometry, each taking two or three class hours per week.

Replace the "packaged" one-year course in physics with a three-year sequence (three class hours per week) developed according to the latest level-by-level theories of learning. The same applies to our one-year chemistry course.

- Introduce a new sequence of courses on "Technology and Engineering" (two to three hours per week), begun in grade nine and offered to all students in all school systems. Whenever possible, the curriculum should combine theoretical and practical studies, ideally using modern, well-equipped shops and laboratories at nearby industrial or commercial enterprises.

- Make optimal use of calculators and microcomputers in the new mathematics program. The ready availability of these tools in the U.S. should be exploited to greatest advantage at all educational levels, starting in the primary grades. In high school, offer separate courses in computer science, statistics and probability, and solid geometry, in addition to the existing courses in advanced algebra and calculus.

- Organize extracurricular programs to develop students' interest in mathematics, science, and technology. These programs should be designed to excite students and ensure the participation of the best teachers and scholars from all school levels, as well as scientists from industry. The programs should be preceded, and then accompanied, by specially prepared literature that makes use of all the available media—books, carefully designed and widely distributed periodicals, and video presentations on tape and disc. The Public Broadcasting System, museums, and other public educational institutions should be encouraged to provide integrated programs and services.

- Organize new programs, and expand existing ones (such as summer programs), for the discovery and training of mathematically talented children from the earliest possible age.

- A prerequisite for all changes, of course, is basic literacy. Innovative courses, sophisticated textbooks, and superior professional guidance will all go for nought if students are unable to read or write. It is therefore essential that we upgrade the graduation requirements for English in high schools to four years. To help create a global perspective and provide the background for an understanding of international relations and foreign cultures, geography (two years), foreign language (two years), world history, and economics should also be included among basic requirements. It might be noted that *teachers* of English in the Soviet Union outnumber *students* of Russian in this country.

- Organize wide-scale professional orientation programs for all age groups, utilizing resources from a range of institutions.

- Organize or expand continuing education programs for adults who need additional training. We must enable individuals to understand and appreciate new developments in science and technology and offer them an opportunity to study in depth. Schools from

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secondary level up should be used, as well as museums and popular media.

- Allow only specialized teachers to teach mathematics and science courses from grades five on.

- Establish ongoing improvement and retraining programs for primary school teachers, especially those who teach arithmetic in grades 1–4. Inservice and preservice programs should be devoted mainly to teaching content, particularly the fundamental concepts of mathematics and science.

- Expand our research community in the psychology of mathematics and science instruction. If we are to accomplish the curricular reforms outlined above, and stimulate and coordinate research efforts, we must create a national R & D center for mathematics learning (not combined with science). The new center should be established at an institution of higher learning, or a consortium of institutions, selected on the basis of quality and the greatest promise of active participation by a range of outstanding mathematics educators, research mathematicians, and specialists in the psychology of learning and teaching mathematics. Similar separate R&D centers for physics, chemistry, and other disciplines should also be established.

- Institute a program for the development of a literature on teaching methodology for all subjects at all levels of the primary and secondary school system. This literature should address both content of instruction and teaching methods. It should make use of the classroom experience of outstanding teachers, modern research in the psychology of learning and teaching, and the theory and use of instructional materials, including audiovisual teaching aids, calculators, and minicomputers. A comprehensive literature of this kind, developed over a long period of time and continually revised and improved, is being used in all communist countries to assist inservice and preservice teachers. Such a literature is completely lacking in the United States.

- Conduct research on the theory, design, and application of various aids—principally visual—in elementary school mathematics instruction. The premise is that much of the available equipment, both older and more recent, has been rendered obsolete by advances in mathematics and psychology. Even such modern tools as filmstrips and slides must be reevaluated in light of new educational goals and conditions. Newly designed equipment has to be subjected to rigorous experimental testing in schools.

- Seek new ways to come to grips with a tremendous shortage of teachers trained to teach mathematics or science. This will mean an even greater reliance on microcomputers, video, and other technology for computer-assisted instruction. Further, we must make more extensive and intelligent use of our abundant instructional resources by committing ourselves to continuous research and experimentation in the psychology of learning and teaching.

- Greatly expand the system of preschool education. Appropriate teacher training programs should be introduced for this level. Children from the age of three or four should become acquainted in an organized way with the concept of numbers, the basic ideas of geometry, and underlying patterns and relationships in mathematics and science.

- Encourage institutions of higher learning (especially state universities) and their colleges of education to reevaluate their activities, and assume new responsibilities and commitments with regard to high-quality teacher training programs and the establishment of close working ties with the elementary and secondary schools in their area.

- Accompany these comprehensive organizational and curricular reforms with research and development programs, giving special attention to integration of the sciences, particularly in their relation to mathematics. This research should be applied to the interrelationships of subjects and the establishment of a logical order of presentation in school curricula at each level.

- Create permanent national curriculum centers and a national review board in science and technology. These bodies should include the nation's top scientists and engineers with educational expertise, researchers, outstanding teachers, educators, and psychologists. They would supervise the development of new curricula and review the implementation of programs and text materials.

We must acknowledge that an educated population and a well-trained work force are essential to the recovery of our country's dynamic spirit and economic strength. Then we must go beyond mere recognition of the problem and mount a serious effort, a genuine *national mobilization* for education.

This will require creativity, energy, and wisdom. Representatives of every segment of American society, from leaders of industry to concerned parents, are looking for national leadership and a decisive program to resolve the current crisis in our education. Society needs guidance, purpose, and hope. It will then be ready to make a strong commitment to an educational revival. To give up, to procrastinate, or to plan only for the short term would be to mortgage our freedom and our future. □

[1] This recommendation was suggested by Benjamin S. Bloom of the University of Chicago.