Is the Quality of American Students Really Declining?

A number of factors contribute to the unacceptably low skill levels of U.S. students, but the education system bears much of the blame. Remedies are available, but they demand major changes and concerted efforts.

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Complaining about the rising generation is not a new pastime. In a frequently cited quotation, the author grumbles that today's young people are ignorant, unmotivated, unruly, unkempt, and generally nothing like the well-educated and hard-working youngsters in *his* day. The punch line is that the quote originated in ancient Rome.

But while such complaints may be perennial clichés, they have at times in history been based in reality, and the social consequences of their possible validity today are becoming increasingly serious. For better or worse, the well-being of our society depends on science and technology. If we are to meet our continuing demands for food, housing, transportation, energy, health care, and environmental protection, we will need a large and steady production of technically competent and socially aware scientists and engineers.

Our ability to maintain this production in the coming decade is in serious jeopardy. The pool of potential scientists and engineers is shrinking: by 2005 the annual shortfall has been projected to be 250,000–700,000 B. S. recipients and 7,500 Ph.D. recipients *(1)*. One reason for the shrinkage is a rapid decline in student interest in science and engineering. Between 1966 and 1988, the proportion of college freshmen planning to major in the sciences and mathematics fell from 11.5 to 5.8% *(2)*, and between 1982 and 1989 freshman enrollment in engineering decreased by 17.2% *(3)*. Compounding the problem is the steady decline of the college-age population since 1983, a decline expected to continue through 1996 for a total drop of about 25% *(3)*.

Moreover, many of those who enter technical curricula drop out. Of students enrolling in science and engineering in 1982, between 30% and 60% (depending on the particular discipline) eventually switched to nontechnical curricula or left college *(2)*. The dropout rate is particularly high for minority students, who constitute an increasing percentage of the total enrollment. For more than a decade, only about 33% of the entering African-American freshman engineering class and about 45% of the entering Hispanic freshman engineering class have completed their degrees *(3)*.

Beyond the numbers, we hear with monotonous regularity that the current generation of American students is materialistic, self-centered, devoid of ideals, unable to read, incompetent in mathematics, scientifically and culturally illiterate, and unable to find anyplace in the world on a map. Although these accusations may be exaggerated, their implications are sufficiently important to warrant considering the extent to which they may be justified. Such a consideration is the goal of this paper. In successive sections, we review published data that reflect on student quality, suggest probable origins of observed quality deficiencies, and propose possible remedies.

Data reflecting on student quality

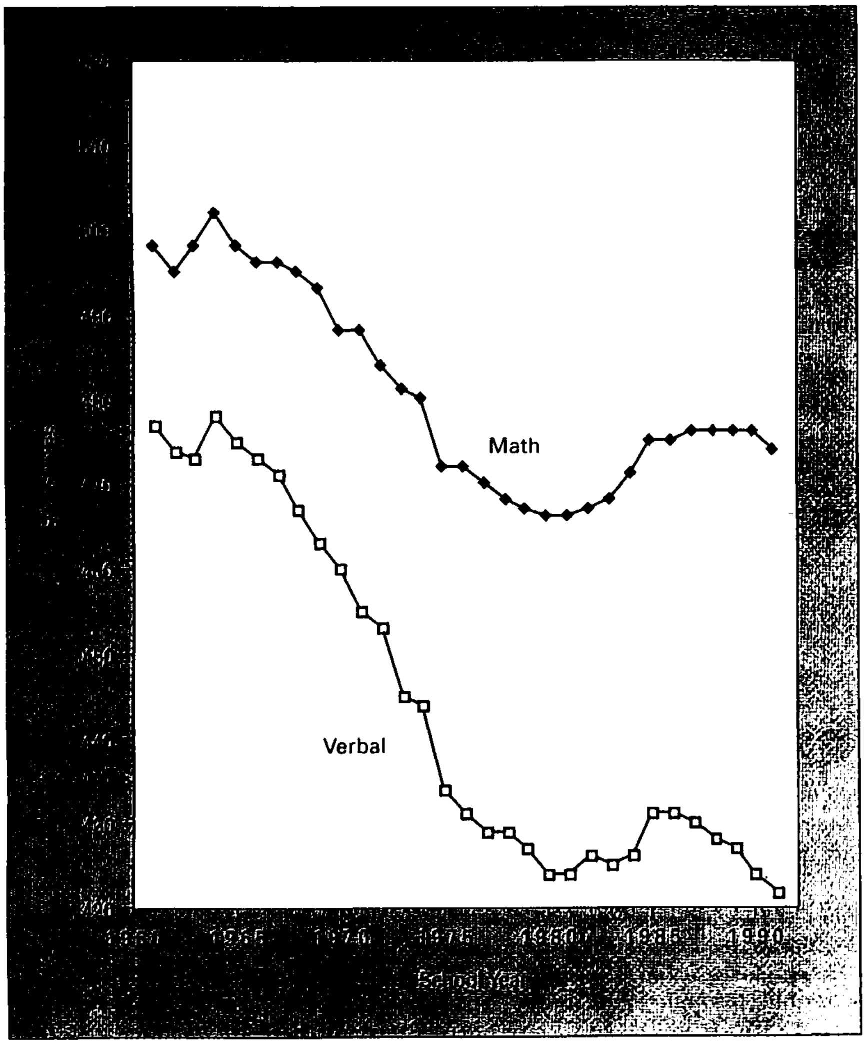
"If an unfriendly power had attempted to impose on America the mediocre educational performance that exists today, we might well have regarded it as an act of war." This chilling assertion *(4)* is supported by standardized test scores over the past three decades, findings from the National Assessment of Educational Progress, and comparative results from international science and mathematics tests. In this section, we summarize these data with minimal commentary, deferring interpretation of the results to later sections. Points especially germane to the subsequent interpretation are italicized.

Standardized test scores. The most commonly cited statistics suggesting a decline in student quality are standardized test scores. Results from several different tests show similar patterns.

• Figure 1 shows nationwide average Scholastic Aptitude Test (SAT) scores over a 30-year period. The mathematics score declined by 36 points from 1964 to 1980, recovered 10 points by 1987, and has stayed relatively constant since then. The verbal score dropped by 54 points from 1963 to 1980, recovered seven points by 1985, and lost nine by 1991. *Equally significant — and perhaps more disturbing — is the performance level of the highest scorers, which was significantly lower in 1982 than 20 years earlier (5).*

• Results from the American College Testing (ACT) examination — the primary college admission test in 28 states — parallel the SAT results. According to data from the ACT Research Service Annual Reports, the average composite score in all subject areas dropped from a high of 20.4 in 1963 to a low of 17.9 in 1975, remained essentially constant through 1983, and climbed back to 18.8 in 1988.

• A third source of data is the Iowa comprehensive testing system, which administers two examinations — the Iowa Test of Basic Skills (ITBS) in grades 3–8, and the Iowa Test of Educational Development (ITED) in grades 9–12. The results for grades 7–12 show the same pattern of decline and partial recovery as do the college entrance examination scores; *In grades 5 and 6, however, the decline is significantly less pronounced, and the scores in grades 3 and 4 show a steady increase from the mid 1950's to 1984 (6).* Although Iowa students are not necessarily representative of the entire nation, the onset of the decline in about the 4th grade and its progressive worsening in higher grades may reflect a national pattern. Other data, as we will discuss, support this inference.



■ *Figure 1. Average SAT scores, 1961–1991.*

The Nation's Report Card. The National Assessment of Educational Progress (NAEP) is a series of tests in different subjects, periodically administered to randomly selected 9-, 13-, and 17-year-olds. Here are findings from the past two decades of this continuing survey *(7–13)*:

• During the period 1970-1990, average NAEP mathematics and reading scores increased slightly or remained constant and science scores decreased and then partially recovered. A 1990 NAEP report notes that "...although some ground lost in the 1970's may have been regained in the 1980's, overall achievement levels are little different entering the 1990's than they were two decades ago." *(10).*

• More revealing than the average scores, however, are the NAEP data on the so-called "anchor levels" — certain scores that NAEP associates with specific levels of achievement. Figures 2–4 show illustrative questions for three anchor levels in science, mathematics, and reading, along with the percentages of students in the 1990 survey who performed at or above these levels. The data show, for example, that only 41% of the 12th graders and 9% of the 8th graders tested could extract information from moderately complex reading passages; fewer than half of the 12th graders and fewer than 10% of the 8th graders could judge the appropriateness of scientific procedures: and roughly half of the 12th graders and fewer than 20% of the 8th graders had an adequate understanding of 7th- and 8th-grade mathematics.

• *The observed deficiencies in students' academic abilities appear to develop progressively over the course of their schooling.* The 1990 NAEP mathematics report notes that "...while 4th graders appeared relatively successful with material covered at the 3rd-grade level, a gap emerged at grade 8, where only two-thirds had a grasp of typical 5th-grade content. For the high school seniors, the gap widened." *(13)* This observation is consistent with the results from the Iowa Test.

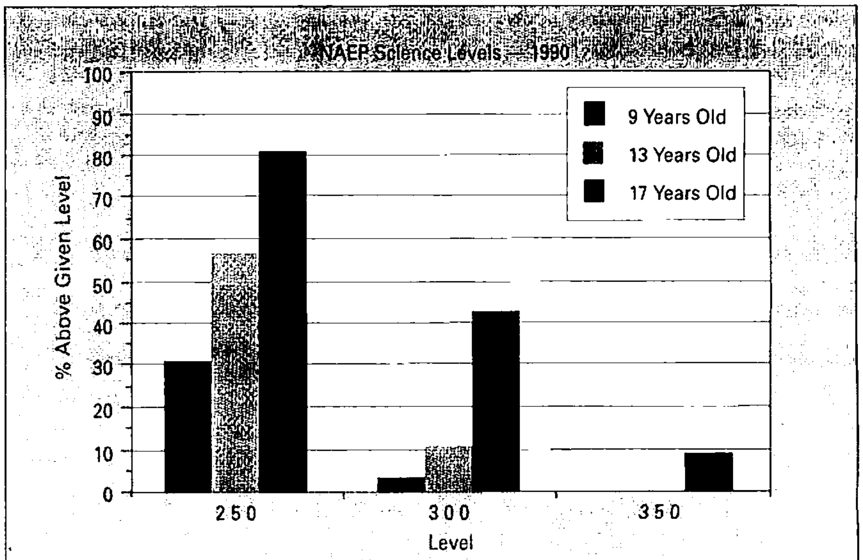
• *In the past 20 years, the trend in all subjects has been toward increasing mastery of basic skills and decreasing mastery of higher-level skills.* Results from the 1988 reading assessment, for example, show that "...the only significant gains in reading proficiency from 1971 to 1988 occurred at the lowest ability levels. Thus, 9- and 13-year-olds were significantly more likely in 1988 than in 1971 to show a grasp of rudimentary or basic reading skills and strategies, and 17-year-olds were more likely to exhibit intermediate skills and strategies. On the other hand, the small percentage of 17-year-old students who demonstrated advanced reading skills and strategies was significantly lower in 1988 than it had been 17 years earlier." *(9)*

Comparisons with other nations. Since the late 1960's, achievement tests in different subjects have been administered to students in several countries. In most of these tests, American students placed at or near the bottom.

• In the 1970 International Science Study, the U.S. placed 14th, coming out ahead of only Chile, India, Iran, and Thailand, as shown in Figure 5. *Even if only the better students (that is, those scoring in the top percentile) are considered, the United States still fell in the bottom half of the participating countries.*

• In the second International Science Study in 1986, U.S. 5th graders scored about average internationally. Ninth graders came out below their counterparts in Australia, Canada, Japan, and every European nation in the study, tied students from Thailand and Singapore, and came out marginally ahead of Hong Kong students. On common items, the American 9th graders did worse than American 9th graders had done in the 1970 study. The scores for 12th graders were equally discouraging: U.S. students correctly answered about 41% of the questions in chemistry and about 44% of the questions in biology and physics, while the lowest score for any other country was 48% for Japan in biology *(14,15)*.

• In the second International Mathematics Test conducted in



Level 250 — Applies basic scientific information

Q: In which pair are both objects made from things that were once alive?

A: Cotton thread and newspaper. (Other choices include china dishes and glass windows.)

Level 300 — Analyzes scientific procedures and data

Q: Which of the following is the best indication of an approaching storm? (A: Barometric pressure decreases.)

Infer that the volume of a block of wood submerged in a graduated cylinder equals the final volume minus the initial volume.

Level 350 — Integrates specialized scientific information

Q: Why are some people worried about recombinant DNA research? (A: Fear of new organisms upsetting ecological balance.)

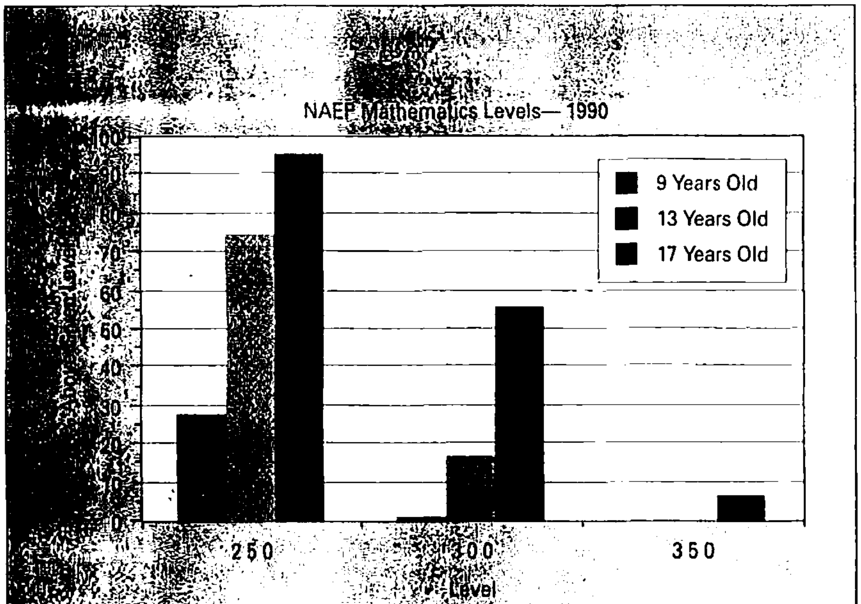
Q: Elements chemically similar to sodium are located where in the periodic table? (A: Above and below sodium.)

From plots of mass (g) vs. volume (ml) for several minerals, determine which minerals would float in water?

Source: *(18)*. The illustrative questions are from a previous test.

■ *Figure 2. NAEP anchor levels — science.*

1981–82, U.S. 8th graders scored at about the international average in three categories and below average on two *(16)*. They were generally above average in calculation but below average in comprehension and problem-solving. *The average algebra score for the top 1% of the American students was lower than the scores for the top 1% from every other country in the study.* The proportion tested of this entire age group in the U.S. — about 13% — was about the same for all countries participating.



Level 250 — Numerical operations and beginning problem solving (all problems multiple choice)

Which is worth more – 11 nickels, 6 dimes, 1 half-dollar?

What is the value of n+5 when n=3?

There are 10 planes on the ground. 6 take off and 4 land. How many are on the ground then?

Level 300 — Moderately complex procedures and reasoning

Is 87% of 10 greater than, equal to, or less than 10?

If 2/25 = n/500, then n = ?

What percentage of 13-year olds scored above Level 300?

Level 350 — Multistep problem solving and algebra

If you borrow $850 for one year at 12% simple interest, how much do you repay?

Which pair of numbers brackets the square root of 17? (A: 4 and 5)

The perimeter of a square is 24 cm. What is the area of the square?

Source: *(18)*. Some of the illustrative questions are from previous tests.

■ *Figure 3. NAEP anchor levels — mathematics.*

• Japanese students consistently come out on top in international mathematics tests. In a test taken by Japanese and U.S. students, Japanese students in their final year of secondary school outscored their U.S. counterparts by a factor of two to three *(17)*. The differences cannot be written off to more selective enrollment in Japan, where over 94% of students enter upper secondary school and 95% of those complete it — much higher percentages than those for the United States.

• In a 1988 study of science and math skills, U.S. 13-year-olds scored last in mathematics achievement and nearly last in science. According to Lawrence Grayson of the Department of Education, "*The only areas in which American students came in first were in the percentage watching five or more hours of television each day and in students' belief that they were 'good' in mathematics*" *(18)*. Results of science and mathematics achievement tests given in March 1991 to 9- and 13-year-old students in 15 countries were no better: again, U.S. scores were lower than those obtained by students in most participating countries. "The plain fact of the matter is our performance is rotten and there are no excuses," said Marc Tucker, president of the National Center on Education and the Economy.

Other performance assessments. In 1983, 13% of American 17-year-olds were rated functionally illiterate (unable to read at the 8th-grade level) and the Department of the Navy reported that 25% of its recent recruits could not read at the 9th grade level, the minimum level needed to read written safety instructions *(4)*. A 1988 estimate put the functional illiteracy figure at 25% of the 2.4 million who graduate from high school each year; the percentage for the one million who drop out each year is undoubtedly much worse *(19)*.

Horror stories about what American students do not know are commonplace features of the daily newspaper. According to recent accounts, many high school seniors did not know that Columbus landed before 1500 (24%); believed that the basic tenet of communism, "From each according to his ability, to each according to his needs" came from the U.S. Constitution (23%); could not specify the half-century in which the Civil War occurred (>40%); were unable to find England, France, South Africa, or Japan on a map (>50%); and thought the sun revolves around the earth (percentage not cited).

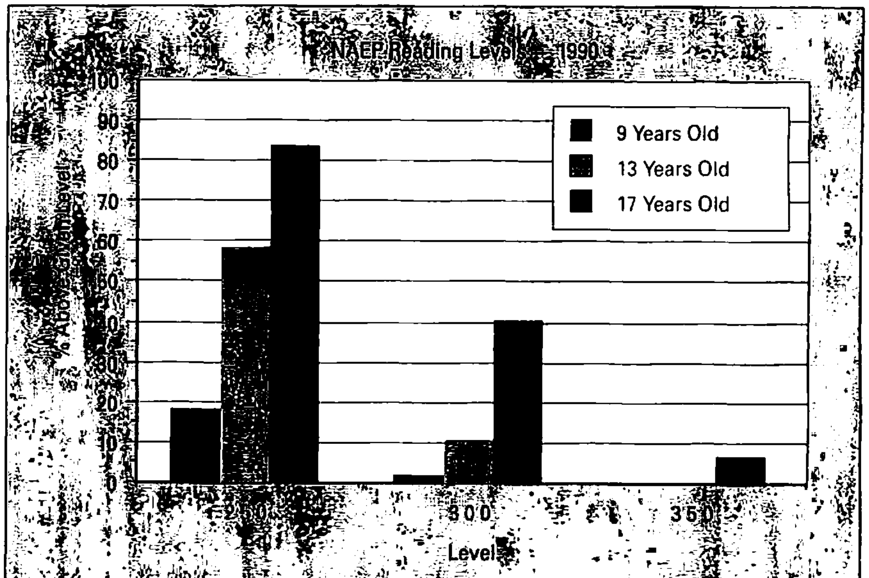
Factors affecting student quality

Poor Teaching. American teachers are overworked, underpaid considering the skilled nature of their profession, undervalued considering their critical importance to society, burdened with nonteaching responsibilities, lacking adequate instructional resources, and sometimes physically endangered. In consequence, science and mathematics teachers are chronically in short supply and new ones tend to be drawn from the low end of the academic spectrum. College graduates in technical fields with even minimal academic credentials can frequently find jobs that pay better and provide better working conditions than does teaching.

In a 1981 survey with 46 states responding, 43 states reported shortages of secondary school mathematics teachers, 42 reported shortages of physics teachers, and 38 reported shortages of chemistry teachers *(20)*. The situation has become worse since then. One million teachers — half the current force — might have to be replaced by the end of the century, while in 1988 only 8% of the nation's 1.6 million college freshmen said that they were interested in teaching and half of them will typically change their minds *(19)*.

The response to teacher shortages is often to bring in underqualified instructors. A 1989 study reported that of the nation's 200,000 secondary-school mathematics teachers, over half do not meet current professional standards for teaching mathematics *(21)*. Some states do not require secondary mathematics teachers to study even up to the level they may teach *(20)*. A 1991 report of the Carnegie Commission on Science, Technology, and Government observes that *more than two-thirds of elementary school science teachers lack adequate preparation in science and more than 80% of mathematics instructors are deficient in their subject.* Indeed, 13 states require no mathematics and science coursework at all for elementary school certification *(18)*.

Weak Curricula. The tendency in American precollege education is to



Level 250 — Interrelate ideas and make generalizations

When Dr. James Naismith, a teacher at the Intl. YMCA School in Springfield, MA, first invented the game...

Q: Who invented the game of basketball?

A: A Massachusetts teacher. (Other choices include a YMCA student and a Los Angeles player.)

Level 300 — Understand complicated information

In 1917 New York followed the example of the western states. In that same year Jeannette Rankin of Montana took office as the first U.S. congresswoman.

Q: In what year did the first U.S. congresswoman take office?

A: 1917. (Other choices include other dates mentioned in the article.)

Level 350 — Learn from specialized reading materials

Members of the court, applying general constitutional provisions, understandably differ on occasion as to their meaning and application.

Q: What does "their" refer to?

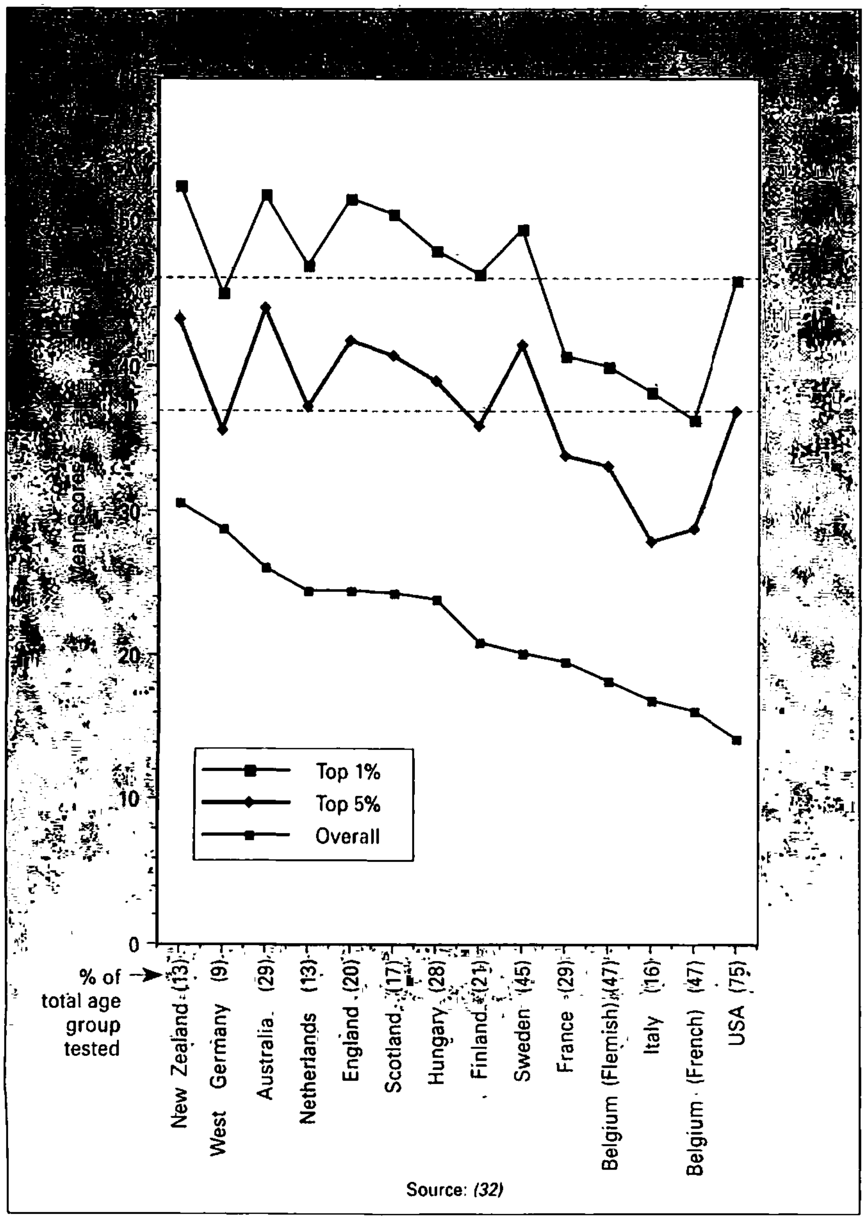
A: Provisions. (Other choices include "Members of the court" and other terms in the preceding sentence.)

Source: *(18)*. The illustrative questions are from a previous test.

■ *Figure 4. NAEP anchor levels — reading.*

teach to the average student. In selected school districts, special programs are available for the academically gifted, but far too few programs to reach all the students who could benefit from them. Providing individualized instruction or multiple tracks within heterogeneous classes would help, but overcrowded classrooms, teachers who have not been adequately trained to deal with heterogeneous ability groups, and lack of instructional resources and administrative support usually make this goal unattainable. The result is that most precollege curricula are weak and undemanding, especially when compared to curricula in other developed countries.

A 1989 study reported that only half of the nation's students take more than two years of high school mathematics and only one-fourth take more than three years *(21)*. Even American students who elect to take four years of mathematics in high school emerge with only about one-third as many hours of mathematics as do their peers in Japan, the former Soviet Union, Germany, and China *(20)*. The burgeoning enrollment in remedial courses in the first year of college reflects the inadequate mathematical preparation of American students: "Everybody Counts" *(21)* states that 60% of all college mathematics enrollment is in courses normally taught in high school.



■ *Figure 5. Results of 1970 International Science Test.*

Figure 6 shows the average class time spent on science by high school graduates in the U.S., the former U.S.S.R., and the People's Republic of China. The dramatic disparities speak for themselves, especially in physics, which Soviet and Chinese students study for about 500 class-hours over a four- or five-year period and American students study for less than 200 hours in one year.

American students also do not read much, either for school or for recreation. According to a NAEP study, more than 50% of the high school seniors surveyed reported reading 10 or fewer pages a day for homework and in class, and more than 30% read five or fewer pages a day *(10)*. In fact, most students do not do much homework at all. Of roughly 2,000 high school students surveyed by "Who's Who Among American High School Students," 56% reported that they study one hour or less per day for all subjects combined.

College enrollment demographics. One piece of good news in the midst of all this gloom is that a growing percentage of Americans are completing high school and going on to college. According to U.S. Bureau of Labor statistics, the percentage of people of age 25 and older completing high school rose from 42% in 1960 to about 77% in 1989, and the percentage completing four years of college increased from 8% to 22% in the same period. Much of the latter increase is probably attributable to an increasing enrollment of students — including many minority students — whose poor academic credentials would have kept them in the past from entering, or even considering, college.

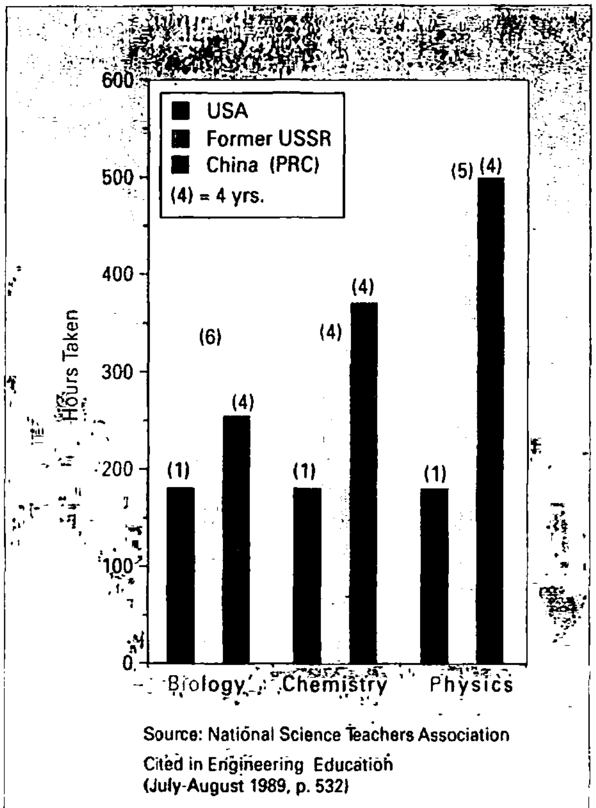
The impact of increased minority enrollments is particularly significant in engineering schools.

Although the percentage of African-American students in the total college population during the period 1970–1990 did not change appreciably, the percentage in entering freshman engineering classes rose from 5.3% in 1976 to 8.9% in 1990. The percentage of Hispanic students rose even more dramatically during the same period from 2.1% to 6.2% according to the Engineering Manpower Commission.

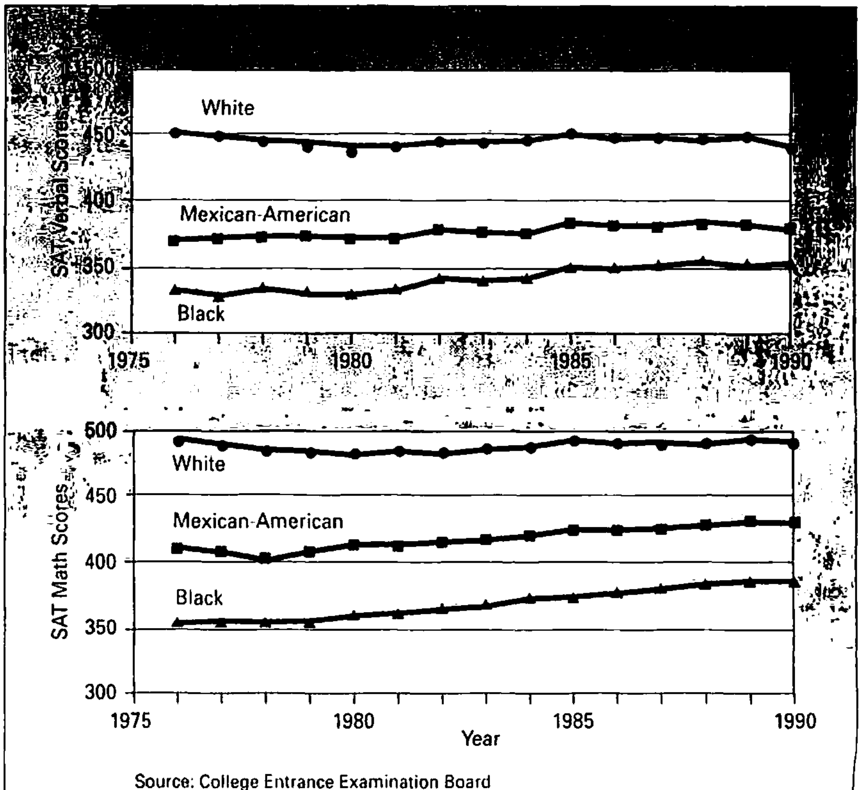
For reasons that have been the subject of extensive but inconclusive speculation, minority students get much lower scores on standardized tests than do white students. Figure 7 shows SAT verbal and mathematics scores by ethnic group. The average verbal score for white students fluctuated within the 440–450 range from 1976 to 1990; the score for Mexican-American students rose from 370 to 380; and that for African-American students rose from 333 to 352. SAT math scores follow similar patterns, as do average NAEP scores over the past two decades. In all cases, differences between white and minority student scores have decreased over the years but remain significant in all subjects for all age groups tested *(11)*.

In short, observed declines in average standardized test scores obtained by entering college students are partially attributable to increased enrollments of minority students. We should applaud the trend toward increased minority enrollment because an expanding flow of minority students into the science and engineering pipeline is essential to the nation's future. But we should also recognize that simply admitting these students is not enough — their academic needs must be recognized and addressed so that most of those admitted go on to graduate.

Sociological factors. The blame for existing student quality problems cannot be laid entirely on the American educational system. The home has a critical role in supplementing and enriching the education provided by the schools, and an even more critical role in nurturing positive attitudes toward learning. For a variety of reasons, decreasing num-



■ *Figure 6. Average time spent on science by high school students.*



■ *Figure 7. SAT scores by ethnic group, 1961–1991.*

bers of American children enjoy home environments that provide such nurturing. Another, perhaps related, phenomenon affecting academic performance is alcohol and drug abuse among school children.

A third contributing factor is television. A 1986 NAEP study found that close to 60% of 17-year-olds and more than 70% of 13- and 9-year-olds surveyed watched television for three or more hours every day *(8)*. The same study also found an inverse correlation between average NAEP mathematics scores and extent of TV watching. In 1986 the average score was 310 for students who watched between zero and two hours per day, about 300 for those who watched between three and five hours, and 282 for those who watched more than six hours per day. Similar patterns were found for NAEP reading proficiency scores *(12)*. Granted, these results do not prove a causal linkage between TV watching and school performance. It is reasonable to conjecture, however, that students will be less likely to respond to traditional classroom lectures if they are accustomed to getting all their information in 30-s bites from a medium that lets them tune out a presentation the instant it stops entertaining them.

What is the real problem?

The data that we have summarized here make it clear that the academic skill levels of American students are unacceptably low, but the primary causes of the observed deficiencies are not quite as clear. We have suggested a variety of possible contributory factors, such as the diminishing role of the American home environment in providing active support for study and learning. There is reason, however, to believe that the American educational system must accept principal responsibility for low student performance levels.

Several observations provide the basis for this assertion. First, observed performance deficiencies appear first in late elementary school and become progressively worse through middle and high school. Second, the deficiencies are consistently more pronounced at the upper end of the performance spectrum. Third, performance is worst among minorities and students from regions of the country such as rural areas and the southeastern United States in which education funding and resources are traditionally below national norms. These results are not consistent with a theory that assigns blame entirely to the home environment, increased drug use, or a general moral laxity among today's youth, all of which might be expected to distribute the problems more or less uniformly among students of all ages, ability levels, and educational backgrounds. The results *are* consistent with the following characteristics of the American educational system:

With all their academic deficiencies, today's college students are the only source of the next generation of American scientists and engineers.

• *A "one size fits all" approach to education, with little or no recognition of the wide range of learning styles, cultural backgrounds, and levels of intellectual capacity and curiosity that characterize every student population.*

Aiming most lectures and homework assignments at students of low-to-average abilities would be expected to result in deficiencies in higher-level thinking skills, such as have been observed. Minimizing the amount and level of science and mathematics instruction, requiring very little reading, and assigning a negligible amount of homework almost guarantees the poor performance observed on high-level NAEP questions and international tests.

• *Weak instructional curricula and inadequate instructional resources, especially in science and mathematics.*

The brightest students in European and Asian countries with whom the United States is technologically and economically competitive get much more science and mathematics instruction than do their American counterparts. Many American schools are characterized by overcrowded and uncomfortable classrooms, inadequate textbooks, and few or no laboratory facilities.

• *A requirement that students do essentially all of their learning by listening to lectures, reading books, and completing individual homework assignments.*

Both controlled research and empirical observation have repeatedly shown that the most effective learning occurs when students take active roles — experimenting, debating ideas, testing hypotheses, and teaching each other in cooperative learning environments *(22,23)*. Nevertheless, students in most classrooms are relegated almost entirely to passive, competitive roles. It is probably not a coincidence that this mode of instruction becomes dominant in about the 4th or 5th grade, just the point at which significant disparities begin to appear between what students have been taught and what they actually know.

• *A severe shortage of qualified teachers in the U.S., caused in part by the low economic and social status and poor working conditions associated with educational careers.*

Even if a school district chose to provide differentiated instruction to students of different ability levels in active and cooperative learning environments, teachers with the training and ability to do it are in critically short supply now and their numbers are shrinking. In science and mathematics, the need is most acute for instructors capable of teaching at advanced levels. The "new math" introduced in the 1960's did not fail because it was intrinsically too difficult, but because most teachers lacked the training and the understanding to make it comprehensible to the students.

Additional evidence that precollege education is primarily responsible for poor student performance is provided by the successes of certain minority engineering programs. The three-year retention rate for African-American students in programs at the University of California was 64%, as compared with a retention rate for nonparticipating African-American students of 13%. Similar results were obtained for African-American students at California State University (participants in minority programs, 79%; nonparticipants, 30%) and for Mexican-American students at both universities (57% vs. 21% at the University of California, 88% vs. 41% at California State University) *(24)*. The defining characteristic of these programs is an active, collaborative learning environment maintained under the direction of skilled instructors. If the presence of these features can lead to such dramatic improvements in student performance, it is reasonable to infer that their absence may account in significant measure for poor performance.

A misguided approach

Unfortunately, many would-be educational reformers ignore or dismiss the data and blame poor student performance on a purported loosening of academic standards that began in the 1960's. A commonly proposed remedy is to go "back to basics," which to many people means to increase repetitive drilling in the basic vocabulary and the science and mathematics facts covered at the lowest levels of standardized tests.

This analysis is simplistic and misguided, however. The decline in college admission test scores that led to much of the back-to-basics rhetoric began to reverse itself in the lower grades in the early 1970's, while the educational reform movements of the 1960's were still in vogue. Moreover, the worst deficiencies — then and now — have not been in low-level skills but in higher-level thinking abilities, which are not addressed by programs that stress basics. Increasing emphasis on basic skills is therefore unlikely to correct the most serious student quality problems now facing us. Neither is the answer a "freedom of choice" policy that would subsidize primarily affluent parents to send their children to private, parochial, and "good" public schools, potentially overburdening those schools and leaving the remaining public schools as dumping grounds for the underprivileged. The question, then, is what *will* help?

A serious impediment is a growing divergence between professors and students.

Short-range solution: the role of universities

It is clear that the ultimate solution to student quality problems does not reside in universities. By the time students reach college they are basically formed. While professors can try to remedy the problems and may even be reasonably effective at doing so, they are at best playing a catch-up game. If the problems are to be solved in the long term, the solutions must be sought in precollege educational reform. Even if reform is successful, however, its effects will not be felt at the college level for several decades. With all their academic deficiencies, today's college students are the only source of the next generation of American scientists and engineers. Helping them overcome those deficiencies is a vital university function.

A serious impediment to the fulfillment of this function is a growing divergence between professors and students. Many entering college students are poorly prepared academically, inadequately motivated to learn, and unable to extract information from lectures and readings. University faculties, on the other hand, are increasingly made up of PhD's who regard themselves primarily as research scholars *(25)*. Mismatches have consequently arisen between the ways most college students learn and the ways most college teachers teach *(26,27,28)*. Students raised on television, used to getting information visually, are force-fed steady diets of lectures and readings. Students who think concretely — who relate best to facts, data, demonstrations — are taught primarily abstractions — generalized theories and mathematical analyses.

It isn't working: many of our students simply cannot absorb material taught in this manner. As a result they may become bored, inattentive, or disruptive in class; get discouraged about the course, the curriculum, or themselves; and change curricula or drop out of school. Instructors see the low test grades, the unresponsive classes, the poor attendance and dropouts, and know something is wrong. They may become defensive or hostile toward the students (making things even worse) or question whether they are in the right profession. Most seriously, society loses potentially excellent professionals.

To remedy these problems, instructors should teach science and engineering courses in a manner at least somewhat compatible with the learning styles of the students *(26)*. In all courses, they should attempt to:

• *Balance concrete information — descriptions of physical phenomena, results from real and simulated experiments, demonstrations, and problem-solving algorithms — with conceptual information — theories, mathematical models, and material that emphasizes basic understanding.* Motivate presentation of theoretical material with prior presentation of phenomena that the theory will help explain and problems that the theory will be used to solve. Teach inductively — give some experimental observations before presenting general principles and have the students see how far they can get toward inferring the latter.

• *Make extensive use in lectures of sketches, plots, schematics, vector diagrams, computer graphics, and* *physical demonstrations in addition to oral and written explanations and derivations.* Most students are *visual learners*, absorbing much more of what they see than what they hear or read. Their immediate recall of material presented in a 50-min dose of words and formulas is likely to be low and their comprehension and long-term retention of that material negligible.

• *Phase out the ancient instructional model in which the professor lectures and writes and the students passively listen and copy, replacing it with an active, cooperative learning paradigm.* Assign brief group problem-solving exercises in class. Encourage or mandate cooperation on homework. Students who participate in cooperative (team-based) learning experiences — both in and out of class — are reported to earn better grades, display more enthusiasm for their chosen field, and improve their chances for graduation in that field relative to their counterparts in more traditional competitive class settings *(23)*.

The idea is not for instructors to attempt to do all of this at once. Rather, they should pick one or two of these techniques and try them in a course, keep the ones that work, drop any that don't, and try one or two more in the next course. They can in this way evolve a teaching style that is both comfortable and effective, with a potentially dramatic effect on the quality of learning that subsequently occurs. It may not be enough to convert all the students into the competent scientists and engineers and the bright, productive, and intellectually curious people we all hope they become, but it could be an excellent start.

Long-range solution: the role of public schools

Before high schools can begin to turn out significant numbers of

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intellectually curious, culturally literate, scientifically competent, and socially conscious graduates, a number of problems will have to be addressed in the precollege educational system:

1. a shortage of qualified teachers;
2. weak instructional curricula and inadequate instructional resources;
3. predominantly passive and competitive classroom environments above about the 5th grade; and
4. a failure to meet the educational needs of the brightest students.

This diagnosis suggests that teachers and principals, boards of education, state legislatures, and public and private educational funding agencies working together might effectively remedy the problems by implementing the following steps:

• *Make the teaching profession attractive to the best of our college graduates.* Offer salaries comparable to salaries earned by professionals in comparably skilled and critical professions, with supplements for teachers in subjects and school districts in which severe shortages exist. Remove nonteaching responsibilities from teachers — cafeteria duty, bus duty, endless paperwork — so they can devote themselves full-time to planning, instruction, and evaluation. Provide functional classrooms and first-rate instructional resources (such as laboratory equipment and supplies, computers, and good instructional software). Empower teachers, giving them the right and responsibility to take an active role in making curriculum decisions and determining academic policies and procedures.

• *Establish active, cooperative learning environments.* Extensive research has shown that lecturing is the least effective instructional method for achieving any educational objective other than short-term retention of facts. When we place students in instructional environments that give them the opportunity to learn actively — running experiments, trying out ideas, discussing, debating, discovering, working in groups, teaching one another — they learn better.

• *Provide differentiated instructional activities and support for different ability levels.* Offer remediation to those who need it, but also give the gifted and talented the stimulation and challenge they need for their abilities to develop and flourish. Improve counseling resources to provide support for those whose home and peer group environments put them at risk academically.

• *Develop cooperative university-school partnerships (29,30) and cooperative business-school partnerships (31) to provide both expertise and financial support to the schools.*

There can be little doubt that all of these steps would move student performance levels in the desired direction. Unfortunately, most of them cost money — much more than loading on more drill and cramming in more facts, which may be economical but are much less likely to accomplish anything useful. Taking all of them will require a major commitment of resources, with provisions that the funding go into improving education and not simply into creating additional layers of administration. Considering the cost to the country of not making the changes, it is a commitment well worth undertaking. CEP

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