Chapter

# Shaping the Science and Engineering Talent Pool

Photo credit: William Mills, Montgomery County Public Schools

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# Chapter 1

# Shaping the Science and Engineering Talent Pool

*To the Committee (the President's Science Advisor-y Committee], enhancing our manpower supply is primarily a matter of quality not quantity, not a matter of diverting more college students to science and engineering, but of providing for more students who have chosen this career route the opportunity to continue their studies.*

Jerome *Wiesner*, ***1963***

All scientists and engineers were once children: Families, communities, and the ideas and images presented by books, magazines, and television helped form their attitudes, encouraged their interest, and guided them to their careers. Schools refined their talents and interests, prepared them academically, and gave them confidence by recognizing their aptitude and achievement.

The importance of families and other out-of-school influences on this process can hardly be overemphasized. Students form opinions and learn about science and scientists from families and friends, from the media, and from places such as science centers and museums, summer camps, and summer research experience. Equally, families, friends, and the media can dull interest in science. Nevertheless, it is largely schools, through preparatory courses in mathematics and science, testing methods, and teaching practices, that determine how many young people will prepare sufficiently well for science and engineering careers (and for other careers). It is in the Nation's interest to see that schools provide the widest possible opportunities, and the best possible educational foundations for the' study of science and engineering.* Some schools meet these goals, but many do not. A small minority of determined students no doubt can triumph over poor teaching, inadequate course offerings, and overrigid or biased ability grouping or tracking. For most—even some of the most talented—these failings of the schools can kill interest and waste talent.

Of particular concern are women and some racial and ethnic minorities, who together represent a large reservoir of untapped talent. Minorities in particular will make up larger proportions of the population in the future. Identifying and motivating talented minority youngsters is an increasingly important necessity for schools.

Concern about the quality of science and mathematics education is also part of a broader concern about the Nation's schools. The objectives, funding, quality, and content of American education are all currently being debated, and a variety of remedies have been proposed.[2]

[1]Unless otherwise noted, this technical memorandum is concerned exclusively with students' interest in *natural* science and engineering subjects. The adequacy of the preparation of future social scientists is not considered.

[2]National Commission on Excellence in Education, A *Nation At* ***Risk*** (Washington, DC: U.S. Government Printing Office, 1983). The sequel, Secretary of Education William Bennett's ***American Education: Making It Work,*** does not quell the concern. Also see National Science Board, ***Educating Americans for the*** 21st ***Century*** (Washington, DC: Commission on Precollege Education in Mathematics, Science, and Technology, 1983); Paul E. Peterson, "Economic and Policy Trends Affecting Teacher Effectiveness in Mathematics and Science," Science Teaching: ***The Report of the 1985 National Forum for School Science,*** Audrey B. Champagne and Leslie E. Hornig (eds. ) (Washington, DC: American Association for the Advancement of Science, 1986).

# PREPARING FOR SCIENCE AND ENGINEERING CAREERS

In theory, the preparation of those intending to become scientists or engineers is assumed to be more intensive than that required of the entire school population. In practice, the interest of both groups must be stimulated. All students need fundamental preparations in mathematics and science in the early years of school. The broad goal of improving the understanding of science and technology by all high school graduates (often called scientific or technological literacy) is very closely tied to that of educating future scientists and engineers. Only at the high school level, where the courses chosen by each stream diverge significantly, does this tie begin to loosen.

## The Pipeline Model

The path by which young people approach careers in science and engineering is commonly visualized as a kind of pipeline. Students enter the pipeline as early as third grade, where they begin to be channeled through a prescribed level and then sequence of preparatory mathematics and science courses. This channeling pervades the undergraduate and graduate studies that train and credential them as professionals. Many students drop out along the way, losing interest or falling behind in preparation. Few, it is generally thought, enter the pipeline after junior high school. In fact, students' intentions remain volatile until well past high school, with substantial numbers entering the pipeline (by choosing science and engineering majors) by their sophomore year of college. Many late entrants are relatively ill-prepared, however, and may suffer attrition on their path to a baccalaureate.

The pipeline model projects the supply of future scientists and engineers on the basis of the demographic characteristics of successive birth cohorts. But this process is complicated. Career choices, perceptions of opportunities, knowledge of employment markets, and other influences draw students into and out of the talent pool. Changing educational standards and practices also influence the size of this pool.

The education system thus can be thought of as a kind of semipermeable, or leaky, pipeline, with many points of entry and exit through which different students pass with different degrees of ease. Entrance to and persistence in this semipermeable pipeline vary with job opportunities as well as with individual propensities toward knowledge and personal fulfillment. In fact, fields of science and engineering offer widely different incentives that reflect economic and social trends. Thus, the semipermeable pipeline should be thought of as branched, with openings into diverse job markets and careers.

## Influences on the Future Composition of the Talent Pool

These observations suggest that the talent pool can be enlarged, and changing demographics suggest that it ***must*** be enlarged. If schools were more generous in identifying talent, and urged college-preparatory mathematics and science courses on more students (not just those who believe they "need" them for career purposes), both the size and quality of the talent pool would be improved. Our scientists and engineers would be more numerous, better trained, and drawn from a population more representative of American society.

Yet the Federal Government is limited in its impact on elementary and secondary education: schools are State and local responsibilities. Research, curriculum development, demonstration projects, equity, and leadership ("jawboning") are traditional Federal roles, but applying the results to classrooms is up to the State education authorities and the 16,000 local public school boards. Change, in this environment, is slow to come. Another reason for a limited Federal role is that science and mathematics education is but one part of a constellation of educational activities. Teaching, testing, and tracking practices are deeply embedded within the schools. Improvements in science and mathematics education are closely related to reforms in education overall.

### Demographic Trends

Almost all of those who will be the college freshmen of 2005 were born by 1987. Knowledge of current birth patterns allows us to make very reliable forecasts of the size and the racial and ethnic composition of the college-age population for the next 18 years, and very good estimates even farther into the future.[3]

There are two prominent trends already apparent. The first is that the number of 18-year-olds is declining, and will bottom out by the mid-1990s. The second is that racial and ethnic minorities today form an increasing proportion of the school age population.[4] However, the absolute number of Black 18-year-olds is currently falling, just like the number of white 18-year-olds (but the Black birthrate remains higher).

In general, America's schoolchildren will look increasingly different from past generations. As Harold Hodgkinson writes:

> . . . there will be a Black and Hispanic (Mexican-American) Baby Boom for many more years. Hispanics will increase their numbers in the population simply because of the very large numbers of young Hispanic females. These population dynamics already can be seen in the public schools. Each of our 24 largest school systems in the U.S. has a "minority majority, " while 27 percent of all public school students in the U.S. are minority. . . . Looking ahead, we can project with confidence that by 2010 or so, the U.S. will be a nation in which one *of three* will be Black, Hispanic, or Asian-American.[5]

What is unclear is how this demographic transition will transIate into college attendance and pursuit of science and engineering degrees. Variations by region and social class, as well as ethnicity, complicate predictions. These are some current trends:

- A continued drop in the number of minority high school graduates who enter college, due to the increased attractiveness of the Armed Forces and disillusionment with the value of a college degree in today's job market. (Overall, college attendance is currently holding level, owing to the increased numbers of older students enrolling and a current small increase in the number of high school graduates. )
- A continuing increase in the size of the Black middle class, whose children enroll in higher education at about the same rate as do the children of white middle-class families.
- Continuing high dropout rates for Hispanics, only about 40 percent of whom complete high school.
- Rising concentrations of Hispanics in the Southwest and California (enrollment in California's public schools is already "minority majority").
- Significant increases in the number of high school graduates in the West and Florida during the next 20 years, along with declines of as much as 10 to 20 percent in New England, the Midwest, and the Mountain States.[6]

## Educational Opportunity and the Demographic Transition

The participation of females, Blacks, and Hispanics in science and engineering has increased substantially during the last 30 years, but is still small relative to their numbers in the general population.[7] Success in preparation for science and

[3] The actual size of the college freshman class is also determined by the number of older people that enter higher education. At the moment, many people older than the traditional college-going age are indeed entering higher education. In 1985, over 37 percent of those enrolled in college were 25 years of age and older. U.S. Department of Education, Office of Educational Research and Improvement, Center for Education Statistics, ***The Condition of Education: A Statistical Report*** (Washington, DC: 1987), p. 122.

[4] U.S. Congress, Office of Technology Assessment, ***Educating Scientists and Engineers: Grade School to Grad School,*** OTA-SET-377 (Washington, DC: U.S. Government Printing Office, June 1988), pp. 8-9.

[5] Harold L. Hodgkinson, ***Higher Education: Diversity Is Our Middle Name*** (Washington, DC: National Institute of Independent Colleges and Universities, 1986), p. 9. Asian-Americans are well represented in science and engineering; they are categorically excluded from OTA's discussion of educationally disadvantaged minorities.

[6] Jean Evangelauf, "Sharp Drop, Rise Seen in Graduates of High Schools, " ***The Chronicle of Higher Education,*** May 4, 1988, pp. A28-A43.

[7] U.S. Congress, Office of Technology Assessment, ***Demographic Trends and the Scientific and Engineering Work Force—A Technical Memorandum*** (Washington, DC: U.S. Government Printing Office, December 1985), ch. 5. Discussion of women and minorities in science and engineering often concerns their low level of participation relative to men and whites. Accurate description of this situation depends on definitions and meanings of the terms "underrepresentation" and "overrepresentation. " The benchmark most often cited for an "equitable" level of participation is one where the ethnic, racial, and sex composition of the science and engineering work force closely approximates that of the general population. But there is no analytical reason why such a balance should exist. Still, this social goal encompasses the widely embraced motives of promoting equal opportunity, maximizing utilization of available talent,

*(continued on* next page)

engineering careers takes commitment, work, and inspiration, all of which the education system is supposed to promote. If achievement testing, tracking, sexism, and racism in the classroom, or some combination of these and other factors, prevent success, it is because the system ignores individual differences in intellectual development and discourages capable students from becoming scientists and engineers. Such an outcome would be tragic for the Nation.

The science and engineering talent pool is not fixed either in elementary or in secondary school. A determined core group is joined by a "swing group" of potential converts to science and by late-bloomers, so that the future supply of students who will take degrees in science and engineering is not determined solely by the size and demographic composition of each birth cohort. The past interest and performance of female and minority students in science and engineering fields is a tenuous basis for concluding that a shortage of scientists and engineers is inevitable. Rather than accept demographic determinism,[8] OTA has chosen to investigate the formation of the science and engineering pool in high school and assess how the structure of schooling identifies, reinforces, and perhaps stifles aspirations to careers in science and engineering.

*Photo credit: Lawrence Hall of Science*

Schools need to adjust to an increasing proportion of minority children.

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and aligning the objectives and conduct of science and engineering with the societal value of broad participation.

Comparisons on minority work force participation should generally be made with regard to age, because racial and ethnic composition varies by birth cohort. Other considerations may include regional demographic variations, enrollment and educational status, and economic status of the reference population. Another difficulty is that "Black," "Hispanic," and "white" are imprecise terms. They are largely an arbitrary, albeit simple, way of classifying a population. There are often bigger differences within each group than there are among the groups. The professional and educational status of various groups deserves a more accurate description than "underrepresentation" and "overrepresentation" convey.

[8]A. K. Finkbeiner, "Demographics or Market Forces?" ***Mosaic, vol.*** 18, No. 1, spring 1987, pp. 10-17.

## HIGH SCHOOL STUDENTS' INTEREST IN SCIENCE AND ENGINEERING

To find out how high school students come to see natural science and engineering as potential careers, OTA analyzed the Department of Education's High School and Beyond (HS&B) database, which describes the progress of a sample of those who were high school sophomores in 1980 by surveying them at 2-year intervals after 1980.' Students in the sample were asked each year their planned majors, if they were to attend college.

OTA found that, as high school sophomores in 1980, nearly one-quarter of students were interested in natural science and engineering majors.

'Valerie E. Lee, "Identifying Potential Scientists and Engineers: An Analysis of the High School-College Transition," OTA contractor report, 1987. The High School and Beyond database also includes data from a sample of high school seniors in 1980. A followup on both of these cohorts was conducted in 1986, but the results were reported too late to be included in the OTA analysis discussed here. This database also includes information on those planning social science majors, but these have not been considered here. For analysis of the 1972 cohort, see Educational Testing Service, ***Pathways to Graduate School: An Empirical Study Based on National Longitudinal Data,*** ETS Research Report 87-41 (Princeton, NJ: December 1987). For an inventory of national databases on K-12 mathematics and science education, see app. A.

As seniors, almost as many were still interested in these majors, although their field preferences had shifted somewhat. Two years later, 15 percent of the original group of students were in college and planning science or engineering majors.[10] However, as the following discussion will show, this 15 percent was not simply the remnant of those who had expressed interest earlier. In fact, only about 20 percent of this 15 percent indicated science and engineering majors at all three time points in this survey. In other words, many were either new entrants to the pipeline altogether or students whose interests in both science and conscience majors were volatile. Another striking finding was the substantial number of "nontraditional" students in that 15 percent; about one-quarter of them had not been in the academic curriculum track of high school, for example.

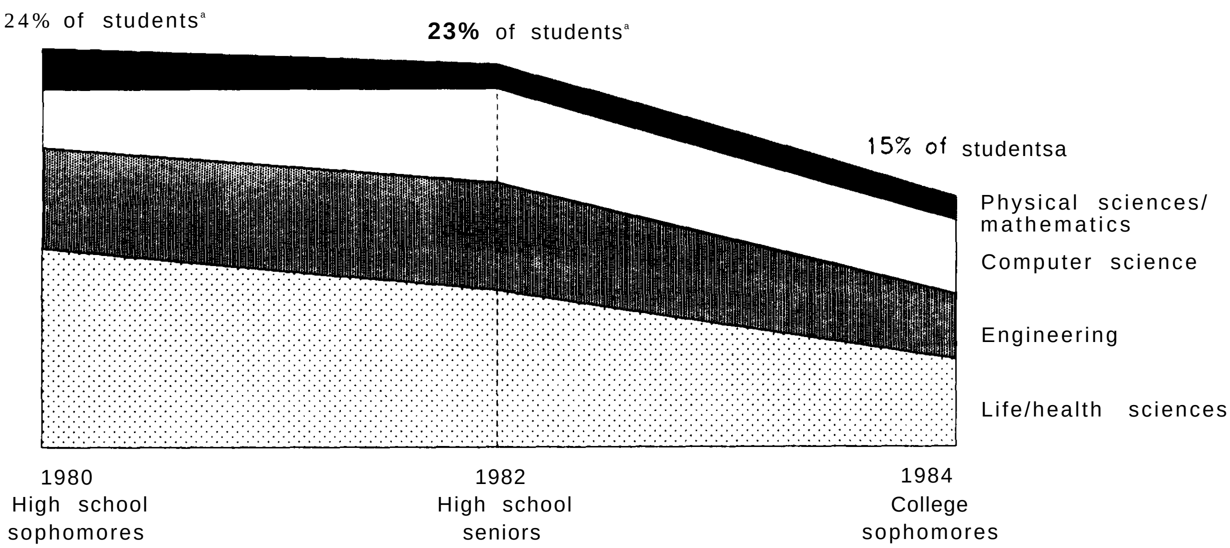
To explore variations in students' interests in different science and engineering fields, OTA defined four broad field categories—health and life sciences, engineering, computer and information sciences, and physical sciences and mathematics." (See figure l-l.) The most popular field

l~o~t of the decline in interest in natural science and engineering majors is due to the overall decline in the proportion of the sample going to college. When a more select group is considered—not just high school graduates, but those who are contemplating attending or are in college—the proportion planning science and engineering majors is 27 percent as high school sophomores, 28 percent as seniors, and 24 percent as college sophomores. Unlike the larger sample of all high school graduates, the more select group of college-bound high school graduates decreases in size over time, as some students who contemplate going to college do not attend, or drop out, and are consequently defined out of the sample at those times (in this case, 1980 or 1982). No data are available on the number of students that subsequently graduated in science and engineering. The sample reported here for 2 years after high school graduation will be referred to as "college sophomores, " even though some were freshmen or not enrolled continuously in college.

[11]Classification of students among fields was based on questions in the High School and Beyond survey and on a reduction to five field categories: life and health sciences, engineering, computer and information sciences, physical sciences and mathematics, and non-science majors. Life and health sciences included those intending medical professions, including nursing. "Technology" majors were not included in the engineering category because students indicating this interest tend to pursue vocational training. Social sciences were excluded from the science field categories and included in non-science majors. Thus, for this analysis, conscience majors included business, preprofessional, social sciences, vocational/technical, and humanities. Social science majors (including psychology) are considered in U.S. Congress, Office of Technology Assessment, "Higher

*(continued on next page)*

**Figure I.I.— Popularity of Selected Fields Among 1982 High School Graduates Intending to Major in Natural Science or Engineering, 1980-84°**




[a]Percent of a nationally representative sample of 1982 high school graduates (n = 10,739) who plan to major in natural science or engineering (NSE). If the sample is restricted to an increasingly select group of only those high school graduates who plan to go or have not ruled out going to college, the percent interested in NSE increases: 27% of high school sophomores (n =9,538), 280/. of high school seniors (n =8,817), and 24°/0 of college sophomores (n =8,583). (The number of college-bound students decreases with time because some students planning college do not attend or drop out.)

SOURCE: Valerie E. Lee, "Identifying Potential Scientists and Engineers: An Analysis of the High School-College Transition. Report 1: Descriptive Analysis of the High School Class of 1982, " OTA contractor report, July 20, 1987, pp. 21-22, Based on data from U.S. Department of Education, High School and Beyond survey.

category at all three time points was health and life sciences. The next most popular field was engineering. In the college sophomore year, engineering was overtaken by computer and information science, which was generally the third most popular field. Physical sciences and mathematics were the least popular potential college majors.

## Persistence and Migration in the Pipeline

Although these data confirm the net loss of students from intended science and engineering majors, they need to be supplemented by data on the number of students who moved into and out of the pipeline. Figure 1-2 documents the flow of students out of and into science and engineering fields, and into the four field categories, over the intervals formed by the three survey points (sophomore year of high school, senior year of high school, and sophomore year of college).

Between sophomore and senior years of high school, the figure shows that, in every field category, more students came into each of the four fields than persisted in them. Movement in from the conscience category was more common than movement between science field categories. Patterns of persistence were less clear during the transition from senior year of high school to sophomore year of college. In all field categories except engineering, more students moved in than persisted.

Overall patterns of persistence are presented in figure 1-3, which shows the proportion of those

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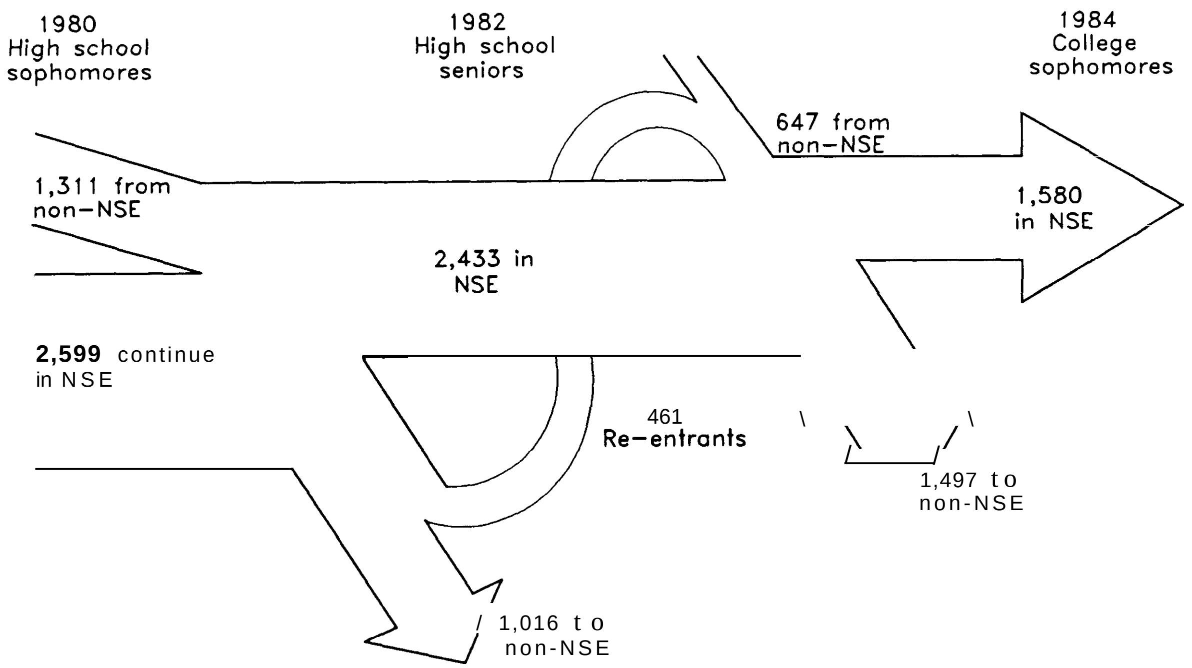
Education for Science and Engineering, " background paper, forthcoming. Movement into and out of specific conscience fields fell outside the purview of this report. However, the data revealed that, within this **category,** a single major—business-engaged an increasing proportion of of **all** students: 10 percent at sophomore year, **13** percent at senior year, and 15 percent in college. No other single major matched the growing appeal of this field.

**Figure 1-2.—Persistence In, Entry Into, and Exit From Natural Science and Engineering By 1982 High School Graduates Planning Natural Science or Engineering Majors, 1980-84**

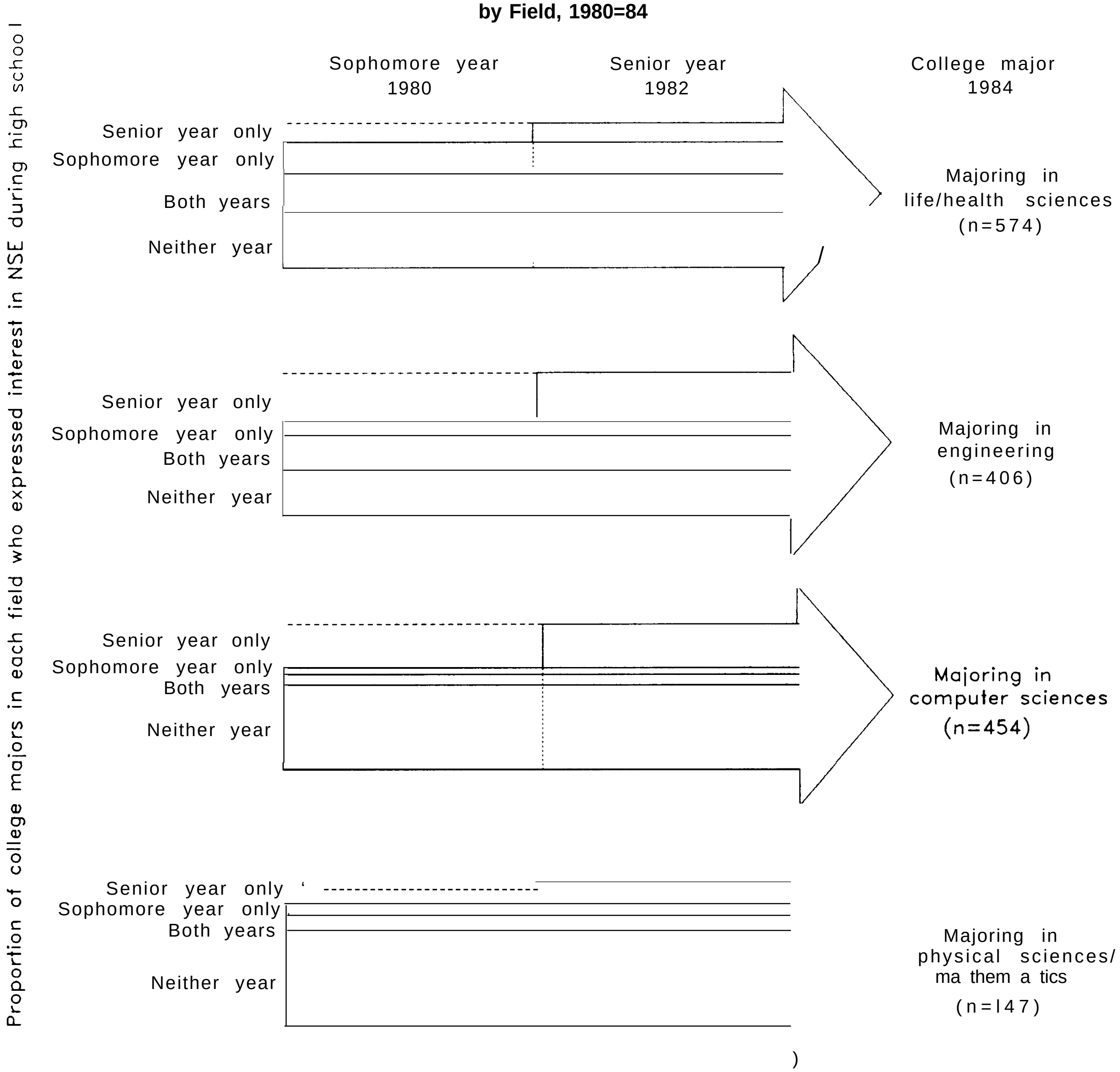



NOTE: This **pipeline** traces those students who, at some point, planned to major in natural science or engineering (NSE), out of a nationally representative sample of high school graduates (n = 10,739). "**Re-entrants**" chose NSE es high school sophomore, "left" NSE es high school seniors, but chose en NSE major in college. Only 300 students, or less than 1O°/., stayed with the same field within NSE at stl three time points; the majority of NSE students changed field preferences *within* NSE at least once.

SOURCE: Valerie E. Lee, "Identifying Potential Scientists and Engineers: An Analysis of the High School-College Transition. Report 1: Descriptive Analysis of the High School Class of 1982," OTA contractor report, July 20, 19S7, pp. 29-35. Based on data from U.S. *Department* of Education, High School and Beyond survey.

college sophomores who were intending to major in natural science and engineering, and had already expressed interest in these field categories at the two earlier time points. A surprisingly small number of students persisted in the same field category at all three time points—about 10 percent in the case of physical sciences and mathematics, and computer and information sciences, and about 25 percent for each of the other two field categories. Students planning engineering majors appear to have been the most persistent, since 60 percent of those declaring this intention during

**Figure 1-3.—Planned Major in High School of College Students Majoring in Natural Science and Engineering, by Field, 1980=84**




NOTE: This figure presents the high school history of college students majoring in natural science and engineering (NSE), showing when they expressed plans to major in their chosen college field. A large proportion of college NSE majors did not plan to major in their chosen field in high school; however, most planned to major in some NSE field, Based on a cohort of students who were high school sophomores in 1980.

SOURCE: Valerie E, Lee, “Identifying Potential Scientists and Engineers: An Analysis of the High School-College Transition. Report 1: Descriptive Analysis of the High School Class of 1982,” OTA contractor report, July 20, 1987, p. 35. Based on data from U.S. Department of Education, High School and Beyond survey.

their high school senior year (and 34 percent of those in the sophomore year of high school) stayed with their plans. *2

OTA's analysis of the HS&B survey shows that natural science and engineering attract some new adherents both in the later years of high school and the early years of college. The die is not cast in the early stages of the educational process; some students (approximately equal in number to those already in the high school science and engineering pool) enter that pool long after many analysts assume that definitive career choices have already been made. The interest is there; the challenge facing educational institutions is to capitalize upon it.

## Academic Preparation of Science and Engineering v. Conscience Students

The challenge of preparing future scientists and engineers is much more than simply sparking interest in students; it calls equally for preparation through coursework and a willingness to bring new entrants to the pipeline "up to speed. " Data on new entrants reveal a mixed picture: many are very well prepared, but others take nontraditional routes and thus require extra help in mathematics and science courses.

Table 1-1 shows some of the characteristics of students planning natural science and engineering majors at the three survey time points. It also shows that the proportion of this group that scored above average on the HS&B achievement test[13] increased at each time point. About two-thirds of those students interested in science and engineering majors in 10th and 12th grades scored above average on these tests, but more than three-quarters of those planning such majors as college sophomores did so. This finding suggests that many of the new entrants to the pipeline are likely to be of high ability.

In addition, the proportion of students planning natural science and engineering majors who had been enrolled in the academic curriculum track increased at each time point until it reached 75 percent in the college sophomore year. Nevertheless, the corollary of this finding—that 25 percent of those seriously planning science and engi-

[12] It is important to note that this figure identifies only those who persisted in the same field category (and not those who persisted in science), although the data indicate few field differences in the numbers of students who entered each field category from conscience majors.

[13] This test score is a composite of scores in reading, vocabulary, and mathematics from tests designed especially for the High School and Beyond survey and administered to the students when they were high school sophomores (in 1980). It has been highly correlated with other achievement tests.

**Table 1-1 .—Academic Characteristics of High School Graduates Planning Natural Science and Engineering Majors and Other Majors, at Three Time Points**

| Characteristic | 1980 high school sophomores | 1982 high school seniors | 1984 college sophomores |
|---|---|---|---|
| ***Students planning natural science and engineering majors:*** | | | |
| Percentage of sample | 24 | 23 | 15 |
| Percentage scoring above 50°/0 on HS&B achievement test | 65 | 69 | 79 |
| Percentage scoring above 75°/0 on HS&B achievement test | 39 | 44 | 53 |
| Academic track | 60 | 64 | 74 |
| General and vocational tracks | 40 | 36 | 26 |
| ***Students planning other majors:*** | | | |
| Percentage of sample | 42 | 38 | 44 |
| Percentage scoring above 50°/0 on HS&B achievement test | 63 | 66 | 67 |
| Percentage scoring above 75% on HS&B achievement test | 36 | 37 | 37 |
| Academic track | 55 | 56 | 60 |
| General and vocational tracks | 45 | 44 | 40 |
| ***Undecided major*** | ***22*** | 21 | 3 |
| ***No college plans*** | ***11*** | ***18*** | ***38*** |

KEY: HS&B=High School and Beyond survey.

SOURCE: Valerie Lee, "Identifying Potential Scientists and Engineers: An Analysis of the High School-College Transition," OTA contractor report, 1987, based on the High School and Beyond survey.

neering majors enrolled in the vocational and general tracks in high school (with presumably less access to college-preparatory courses inmathematics and science)—indicates that the science and engineering pipeline contains some latecomers. Significant numbers of students are active participants in the college segment of the science and engineering pipeline without two of the traditional credentials of a future scientist and engineer: high ability manifested early on and academic track preparation.]'

In a separate analysis (see table 1-2) of students who entered the pipeline from conscience fields, either in their high school senior or college sophomore years, OTA found that these students, on average, had lower scores on achievement tests than did those who persisted in science at all three time points. The "in-migrants" to science and engineering majors had taken fewer mathematics and science courses and were more likely to be Black, Hispanic, or female than their "determined" science peers. Nevertheless, 70 percent of the immigrants had been in the academic curriculum track and had high school and college grade point averages (GPAs) comparable to those who persisted in science and engineering throughout.

In a further comparison of those who switched from a conscience to a science field during their last 2 years of high school with those who persisted in a conscience field (see table 1-3), statistically significant differences were found in the course-taking patterns of the two groups. Immigrants to the science and engineering pipeline were more likely to have taken algebra II, calculus, chemistry, physics, or biology than their conscience peers, and subsequently recorded higher GPAs in mathematics and science courses. Still, they were on average less well prepared than those who stayed with science plans from their high school sophomore to their college sophomore years.

The analysis of the high school class of 1982 illuminates several findings that demand rethinking of how the science and engineering pool forms. Taken together, these findings lend support to the recent observation of the National Academy of

"Nevertheless, the High School and Beyond data for 1980 high school sophomores had not yet followed through to college graduation, and so cannot be used to estimate what proportion of this "nontraditional" group succeeded in earning science and engineering baccalaureates.

**Table 1-2.—Comparison of Students Who Persisted in Natural Science and Engineering With Those Who Entered These Fields, From High School Sophomore to College Sophomore Years, 1980-84**

| Characteristic | Persisted in same field N = 298 | Persisted in NSE, but switched fields N = 277 | Entered NSE from a conscience field N = 1,004 |
|---|---|---|---|
| ***Demographic characteristics:*** | | | |
| Percent Black | 7 | 9 | 15 |
| Percent Hispanic | 5 | 9 | 10 |
| Percent female | 47 | 30 | 48 |
| ***High school experiences:*** | | | |
| Number of math courses taken | 3.1 | 3.0 | 2.7 |
| Number of science courses taken | 3.5 | 3.3 | 3.0 |
| GPA in math courses | 2.7 | 2.8 | 2.7 |
| Score on HS&B Achievement Test[a] | 58.5 | 58.3 | 55.0 |
| Score on mathematics portion of SAT/ACT tests[b] | 516 | 541 | 500 |
| ***College experiences:*** | | | |
| College GPA | 2.8 | 2.8 | 2.8 |
| Percent attained college sophomore status by 1984 | 90 | 76 | 75 |

[a]On HS&B Achievement Test, mean score = 50, standard deviation = 10
[b]Score is presented on same scale as the mathematics portion of the SAT, where students had taken the ACT mathematics test, their SCOW was converted to an equivalent score on the SAT scale

KEY: GPA = grade point average
HS&B = High School and Beyond survey
SAT/ACT = Scholastic Aptitude Test) American College Testing program
NSE = natural science and engineering

SOURCE Valerie Lee, "Identifying Potential Scientists and Engineers An Analysis of the High School -College Transition," OTA contractor report, 1987, based on the High School and Beyond survey

**Table I-3.—Comparison of Students Who Persisted in Conscience interest With Those Who Entered a Naturai Science and Engineering Major, From High School Sophomore Through Coiiege Senior Years, 1980-84**

| Characteristic | Persisted with a conscience field N = 2,337 | Entered a natural science and engineering major N = 799 |
|---|---|---|
| Percent female | 65 | 53[b] |
| Percent Black | 8 | 11[b] |
| Percent Hispanic | 9 | 10 |
| Score on HS&B achievement test. | 53.8 | 54.0 |
| Percent unacademic track | 61 | 63 |
| Mathematics GPA | 2.3 | 2.5[b] |
| Science GPA... | 2.5 | 2.6[b] |
| ***Courses taken (percetage with 1 year or more)*** | | |
| Mathematics | | |
| Algebra 1 | 71 | 70 |
| Geometry | 55 | 59 |
| Algebra 2 | 35 | 44[b] |
| Trigonometry | 21 | 25[b] |
| Calculus | 4 | 13[b] |
| Computer programming | 4 | 5[b] |
| Science | | |
| Biology 1 | 54 | 56 |
| Advanced biology | 15 | 21[b] |
| Chemistry | 27 | 39[b] |
| Advanced chemistry | 3 | 7[b] |
| Physics 1 | 11 | 26[b] |
| Advanced physics | 1 | 3[b] |

[a]On HS&B Achievement Test, mean score = 50, standard deviation = 10.
[b]Indicates that the difference between the two groups was statistically significant at $p < 0.05$.
NOTE: Percentages are rounded to the nearest whole number.
KEY: GPA = grade point average.
HS&B = High School and Beyond survey.
SOURCE: Valerie Lee, "Identifying potential Scientists and Engineers: An Analysis of the High School-College Transition," OTA contractor report, 1987, based on the High School and Beyond survey.

Science's Government-University-Industry Research Roundtable:

> There are no magic one or two points in a student's life that are-crucial to career choice. At every educational and developmental stage factors come into play that shape and reshape the occupational direction a student is taking. Moreover, the influences affecting different groups vary.[15]

[15]Government-University-Industry Research Roundtable, *Nurturing Science and Engineering Talent* (Washington, DC: National Academy Press, 1987), p.34.

## INTEREST AND QUALITY OF SCIENCE= AND ENGINEERING-BOUND STUDENTS

Interest in science and engineering, clearly, is not enough. The ultimate health of the science and engineering work force also depends on another key factor—the quality of students.[16] Science and engineering majors have traditionally had above average GPAs, college admission test scores, achievement test scores, and other markers of quality.

[16]There is little agreement on how the "quality" of high school students should remeasured.Achievement test scores are only one indicator. Just as important are students' understanding oftheprocess of science, attitudes toward science and engineering, language skills, and learning how to learn more effectively. Because there are no consistent data on these latter attributes, achievement test scores are here used as proxy for quality.

In recent years, somewhat fewer college freshmen with "A" or "A-" high school GPAs have chosen science and engineering majors, while increasing numbers name preprofessional and business majors. Yet the proportion of science- and engineering-bound students who score above ***650*** (of a maximum of ***800)*** on the Scholastic Aptitude Test (SAT) mathematics test[17] has increased somewhat between 1975 and 1984. About 44 percent of those who score above the 90th percentile on the SAT mathematics test say they plan science and engineering majors. The average score of all those scoring above the 90th percentile on the SAT mathematics test increased from 623 to 642 in the last 5 years.[18]

It is widely believed by college educators that the quality of high school students who are planning science and engineering majors may be declining compared to their predecessors. While this belief has probably been held by all teachers who try to transmit knowledge to their juniors, there is little evidence to support it. Although SAT scores are an imperfect measure of the quality of students, the average SAT score of all students planning science and engineering majors declined between 1975 and 1983 (parallel to the decline in scores of the entire population of test-takers during the period from 1963 to 1981). The SAT scores of this group, however, have risen somewhat since 1983. The sources of increases and decreases in SAT scores provoke complicated and controversial debates in educational assessment, but there is some consensus that about one-half of the long-term decline during the 1960s and 1970s in the SAT scores was due to changes in the composition of the population of students taking the test. The remaining decline has been attributed to decreased emphasis on academic subjects by schools, and social factors. The recent increases are even less well understood."

Overall interest in science and engineering appears to have increased since the time of the major longitudinal study centering on the high school class of 1972.[20] Since that time, there have been considerable shifts among fields within the science and engineering majors, often in response to employment markets. For example, the late-1970s and early -1980s saw a rapid increase in interest in engineering and computer science majors (freshman interest and college enrollment in engineering approximately doubled during that time), but some decline of interest in physical science majors.

## International Comparisons

There is also current concern that America's best students are of inferior quality compared with their peers in other countries. Two recent international comparisons of achievement scores largely support this concern, but do not definitively explain the causes of these differences (although they suggest the curriculum as a culprit). In particular, interpretation of these data is complicated by major differences in the structure of education in different countries. (More detail on the mathematics and science educational systems of other countries is found in app. B.)

International comparison data are available from the Second International Math Study (SIMS) from 1981 to 1982, and the Second International Science Study (S1SS) from 1983 to 1986.[2'] These

[17]However, many science- and engineering-bound students take the American College Testing program test instead of the Scholastic Aptitude Test. Data on the science- and engineering-bound among the American College Testing program takers are not available.

[18]In particular, there are indications that highly talented white males, a traditional source of scientists and engineers, are increasingly being attracted to these majors. Mechanisms for increasing this group's participation need to be devised as well as those to increase the participation of women and minorities. See Office of Technology Assessment, op. cit., footnote 11. Also see National Science Board, ***Science and Engineering Indicators 1987*** (Washington, DC: U.S. Government Printing Office, 1987), pp. 24-25, app. table 1-7.

[19]National Science Board, ***Science Indicators: The 1985 Report*** (Washington, DC: U.S. Government Printing Office, 1985), p. 128. National Science Board, op. cit., footnote 18, p. 22. ***See*** also U.S. Congress, Congressional Budget Office, ***Educational Achievement; Explanations and Implications of Recent Trends*** (Washington, DC: U.S. Government Printing Office, August 1987).

[20]T.L. Hilton and V.E. Lee, "Student Interest and Persistence in Science: Changes in the Educational Pipeline in the Last Decade, " ***Journal of Higher Education,*** vol. ***59,*** September / October 1988, pp. 510-526.

[21]These studies were conducted under the auspices of the International Association for the Evaluation of Educational Achievement, a nongovernmental voluntary association of educational researchers. See International Association for the Evaluation of Educational Achievement, ***Science Achievement in Seventeen Countries: A Preliminary Report*** (Oxford, England: Pergamon Press, 1988); Willard J. Jacobson et al., ***The Second IEA Science Study–U.S.,*** revised edition (New York, NY: Columbia University Teachers College, September 1987); Curtis C. McKnight et al., ***The Underachieving Curriculum: Assessing U.S. School Mathematics From an International***

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data indicate that the performance in most science and mathematics subjects of U.S. science- and engineering-bound students is inferior to that of their counterparts in many other countries, including Japan, Hong Kong, England and Wales, and Sweden. One finding from the science studies is that the proportion of each nation's cohort of 18-year-olds who take college-preparatory science *courses* is apparently smaller in the United States than in other countries.[22]

Data from the first international mathematics and science studies (done in 1964 and 1970, respectively) indicate that the United States lagged behind other nations even then. For example, in the first international science study, students in Australia, Belgium, England and Wales, Finland, France, the Federal Republic of Germany, the Netherlands, Scotland, and Sweden scored above their peers in the United States (Japan did not participate). And, in the similar mathematics study, students in the United States scored lower than all of the above countries as well as Japan. Because there were few common test items between the first and second tests, and because data on the demographic and other characteristics of the groups tested were not collected at both time points, it is difficult to determine reliably from these studies whether achievement in the United States (or in any other country) has improved or declined. These studies suggest that, compared with other countries, the United States has fared, and continues to fare, poorly in the mathematical and scientific preparation of its future work force.

## Interest in Science and Engineering Among Females and Minorities

Females and the members of some racial and ethnic minorities are represented in most fields of science and engineering in numbers far below their shares of the total population, a difference that emerges well before high school .23

Female interest in science and engineering *is* concentrated in the life and health sciences, and less so in more quantitative fields such as engineering and the physical sciences and mathematics (figure 1-4). Black and Hispanic high school seniors are about one-half as likely to be interested in careers in the physical sciences and mathematics as whites, and Blacks are about one-half as likely to be interested in engineering (figure 1-5).[24] Some of this difference may be due to the fact that Blacks and Hispanics are less likely to go on to college than whites.

Why are females and minorities less likely than males and whites, respectively, to major in science or engineering? What can be done about it? Discussion of these issues arouses vigorous debate, which stems in part from deeply embedded social attitudes and expectations about the roles and contributions of females and racial and ethnic minorities to American society, the professions, and specifically to the science and engineering work force .25

### Differences Between the Sexes in Interest in Science and Engineering

There are considerable differences by sex in the number of students interested in science and engineering fields. Of those interested in life and health

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*Perspective* (Champaign, IL: Stipes Publishing Co., January 1987), pp. 22-30; F. Joe Crosswhite et al., Second ***International Mathematics Study: Summary Report for the United States*** (Washington, DC: National Center for Education Statistics, May 1985), pp. 4, 51, 61-68, 70-74; Robert Rothman, "Foreigners Outpace American Students in Science, " ***Education Week,*** Apr. 29, 1987, p. 7; Wayne Riddle, Congressional Research Service, "Comparison of the Achievement of American Elementary and Secondary Students With Those Abroad—The Examinations Sponsored by the International Association for the Evaluation of Educational Achievement (IEA), " 86-683 EPW, June 30, 1986.

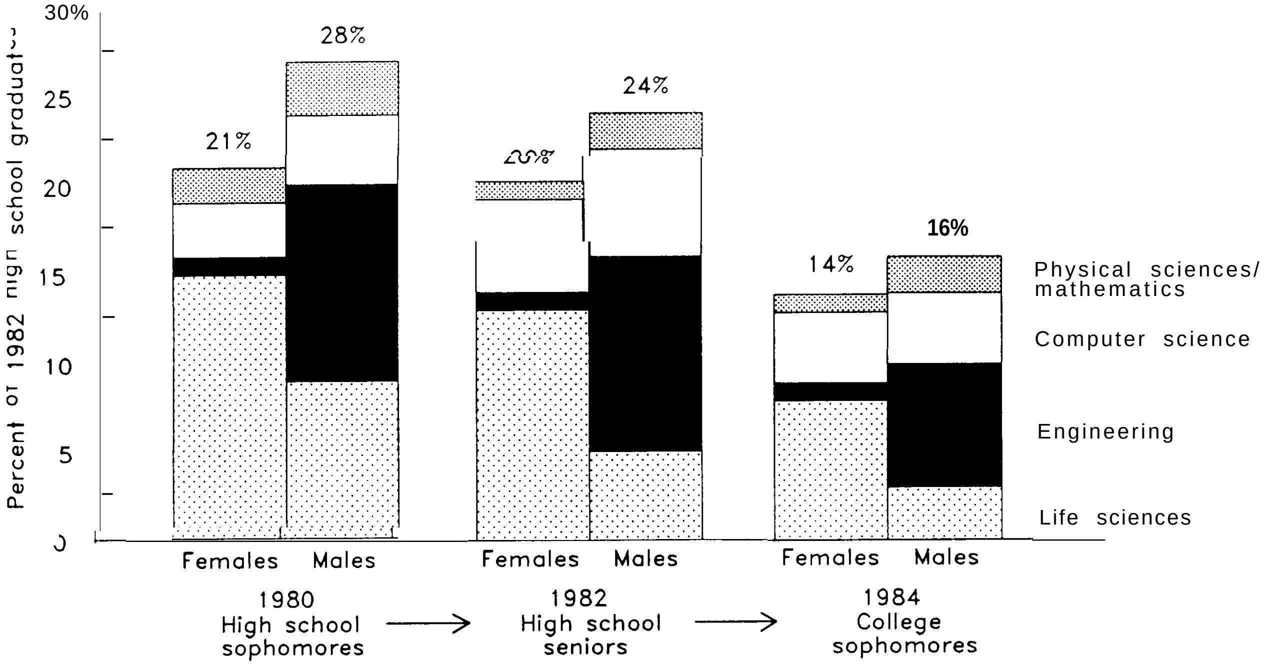
[22]For example, in these data, only 1 percent of American high school students are reportedly enrolled in chemistry and physics, but this refers only to seniors in high school who had taken second year chemistry and physics, not all students who took these courses (Richard M. Berry, personal communication, August 1988). In Canada, the numbers are 25 and *19* percent for chemistry and physics, respectively, and, in Japan, 16 and 11 percent, respectively. Note, however, that these enrollment data for the United States paint a considerably more pessimistic picture than earlier data on course-taking patterns has revealed (see ch. 2), and, due to small sample sizes, are subject to considerable uncertainty.

[23]For an overview, see office of Technology Assessment, op. cit., footnote 4, chs. 2 and 3.

[24]Lee, op. cit., footnote 9.

[25]See, for example, Sandra Harding and Jean F. Barr (eds. ), Sex ***and Scientific Inquiry*** (Chicago, IL: University of Chicago Press, 1987); Willie Pearson, Jr. and H. Kenneth Bechtel (eds. ), ***Education and the Coloring of American Science (New*** Brunswick, NJ: Rutgers University Press, forthcoming); Marlaine E. Lockheed et al., Sex ***and Ethnic Differences in Middle School Mathematics, Science, and Computer Science: What Do We Know?*** (Princeton, NJ: Educational Testing Service, May 1985).

**Figure I-4.–Interest of 1982 High School Graduates in Natural Science and Engineering, by Sex, 1980-84**




NOTE: This is a nationally representative sample of high school graduates (female n = 5,466 and male n = 5,273) who were high school sophomores in 1980. If the sample is restricted to an increasingly select group, of only those high school graduates who plan to go or have not ruled out going to college, the percent interested in natural science and engineering increases: 33% of male and 22% of female high school sophomores, 31% of male and 23% of female high school seniors, and 28% of male and 21% of female college sophomores. (The number of college-bound students decreases with time because some students planning college do not attend or drop out.)

SOURCE: Valerie E. Lee, "Identifying Potential Scientists and Engineers: An Analysis of the High School-College Transition. Report 1: Descriptive Analysis of the High School Class of 1982," OTA contractor report, July 20, 1987, p. 23. Based on data from U.S. Department of Education, High School & Beyond survey.

sciences, about one-half are males and one-half females. Many fewer females, however, are interested in fields with a significant mathematical component, such as physics, chemistry, and engineering. Interestingly, at the baccalaureate level, females are well represented in mathematics itself.

Males and females appear to differ strongly in their interest in highly quantitative sciences. Somewhat more males than females enroll in high school courses leading to these fields, but not so many more as to explain the size of the difference in interest between the sexes. Females also tend to score lower on mathematics achievement tests, even when allowances are made for the fewer courses they take compared to males. The exact causes of these differences in interest, course-taking, and achievement test scores have not been determined and remain a controversial subject for research.[26]

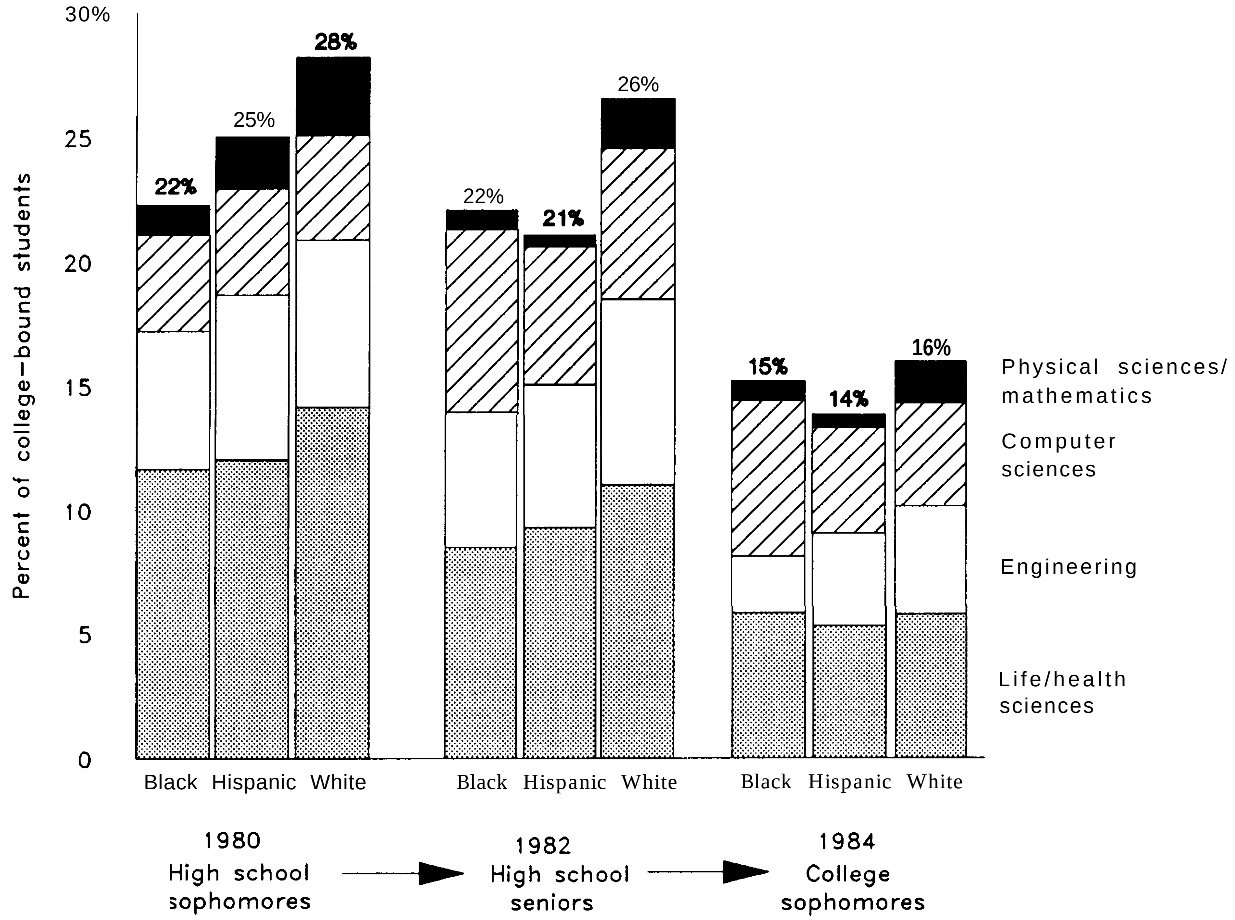
Many researchers believe that the differences are primarily or totally caused by the differential treatment that boys and girls receive from birth. Parents, friends, teachers, and counselors, it is argued, encourage males to be interested in mathematics and science and discourage females. Over time, females come to feel less confident than males about mathematics, come to believe that they do not have mathematical "talent," study mathematics less intensively, and hence score lower on achievement tests. Interest in this "environmental" hypothesis has led researchers to try to ascertain whether sex differences in interest or test scores can be related to these factors.[27]

[26]For a recent overview, see Valerie E. Lee, "When and Why Girls 'Leak' Out of High School Mathematics: A Closer Look," presented at the annual meeting of the American Educational Research Association, San Francisco, CA, April 1986 (unpublished paper available from ERIC). Research that proclaims the biological inferiority of females in mathematical (especially spatial) domains has been seriously questioned (discussed below).

[27]For example, see patncia B. Campbell, "What's a Nice Girl Like You Doing in a Math Class?" *Phi Delta Kappan*, vol. 67, No. 7, March 1986, pp. 516-520. According to a recent national survey,

(continued on next page)

**Figure 1-5.–Interest in Natural Science and Engineering by College= Bound 1982 High School Graduates, by Race.Ethnicity, 1980-84**




NOTE: The sample is limited to those high school graduates who, as high school sophomores in 1980, planned to go to or had not ruled out attending college (white n =7,541; Black n = 1,321; Hispanic n =760). If the sample is restricted even further to those students who stay in the college pipeline after high school sophomore year, the percent interested in natural science and engineering increases; among college sophomores, to 260/. of Blacks (n = 718), 24°/0 of Hispanics (n =434), and 230/. of whites (n =5,208).

SOURCE: Valerie E. Lee, "Identifying Potential Scientists and Engineers: An Analysis of the High School-College Transition. Report 1: Descriptive Analysis of the High School Class of 1982," OTA contractor report, Juiy 20, 1987, pp. 24-26. Based on data from U.S. Department of Education, High School and Beyond survey.

Others maintain that the differences are much more pervasive than can be explained by differential patterns of treatment and, therefore, that physiological differences between the sexes are at work. At the beginning of the decade, one study suggested that differences in the structure and function of the brain allow males to visualize spatial relationships better than females.[28] This hypothesis was based on analysis of scores on the mathematics portion of the SAT (a test designed for 11th and 12th graders) achieved by samples of highly talented 8-year-old males and females.[29] This hypothesis has been roundly criti-

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few students agree that mathematics is a subject more for boys than girls. In 1986, 6 percent of 13-year-olds and 3 percent of 17-year-olds agreed with this statement, although each of these percentages had increased from 2.5 and 2.2 percent, respectively, in 1978. See John A. Dossey et al., ***The Mathematics Report Card: Are We Measuring Up? Trends and Achievement Based on the 1986 National Assessment*** (Princeton, NJ: Educational Testing Service, June 1988), pp. 98-99.

[28] C.P. Benbow and J.C. Stanley, "Sex Differences in Mathematical Ability: Factor Artifact?" ***Science,*** vol. 210, 1980, pp. 1262-1264; C.P. Benbow and J.C. Stanley, "Sex Differences in Mathematical Reasoning Ability: More Facts," ***Science, vol.*** 222, Dec. 2, 1983, pp. 1029-1031.

[29] A representative criticism is found in A.M. Pallas and K.A. Alexander, "Sex Differences in Quantitative SAT Performance: New

cized by many researchers on several counts and is not widely accepted.

It is unlikely that the controversy over the *origin* of gender-related differences in demonstrated mathematical ability will be resolved any time soon, as so many different factors must be controlled in studies making male-female comparisons. OTA concludes that effective steps can be taken to encourage females to enter science and engineering without detailed knowledge of the reasons for sex differences in mathematics achievement and for interest in science and engineering.

There is no evidence that the *rate* of learning of mathematics by males and females is different. *If* there are differences in the preparation for, orientation to, or talents of males and females in science, they can be remedied. Among such remedies are programs to sensitize parents, teachers, and counselors to their conscious and unconscious differential treatments of boys and girls.[30] Schools, and especially guidance counselors, can help significantly by encouraging females who do well in mathematics to take advanced mathematics courses. Schools should also encourage females to participate fully in hands-on scientific experiments. The encouragement of females to pursue science and engineering careers must counter continuing and pervasive, albeit decreasing, discrimination against females in the science and engineering work force, as indicated by lower salaries for new graduates and fewer females in tenured faculty positions.

Evidence on the Differential Coursework Hypothesis, " ***American Educational Research Journal,*** vol. 20, No. 2, 1983, pp. 165-182. For a review of studies and instructive methodological commentary on the debate, see Susan F. Chipman and Veronica G. Thomas, "The Participation of Women and Minorities in Mathematical, Scientific, and Technical Fields, " ***Review of Research in Education,*** Ernst Z. Rothkopf (cd. ) (Washington, DC: American Educational Research Association, 1987), pp. 403-409.

[30]Myra Pollack Sadker and David Miller Sadker, Sex ***Equity Handbook for Schools (New*** York, NY: Longman, 1982); Jane Butler Kahle and Marsha Lakes Matyas, "Equitable Science and Mathematics Education: A Discrepancy Model, " ***Women: Their Underrepresentation and Career Differentials*** in ***Science and Engineering,*** Linda S. Dix (cd. ) (Washington, DC: National Academy Press, 1987), pp. 5-41.

*Photo credit William Mills, Montgomery County Public Schools*

Females and minorities are an undertapped source of scientists and engineers.

## Reasons Why Minorities Are Not Well Represented in Science

Blacks show interest in science and engineering and, in particular, in careers in engineering, mathematics, and computer science .31 The challenge is to convert this interest into well-prepared future scientists and engineers.

Development of interest and talent in science and engineering by Blacks is stultified by their relatively lower average socioeconomic status and more limited access to courses that prepare them for science and engineering careers. Minorities also sense hostility from the largely white science and engineering work force and develop low expectations for themselves in science and mathematics courses. For some, sadly, success in academic study is scorned by their minority peers as "acting white. " Larger proportions of minorities drop out of high school than do whites, reducing the potential talent pool for science and engineering. And far fewer Black males than Black females prepare for college study, a pattern which is increasingly common as Black males favor military

"Jane Butler Kahle, "Can Positive Minority Attitudes Lead to Achievement Gains in Science? Analysis of the 1977 National Assessment of Educational Progress, Attitudes Toward Science, " ***Science Education,*** vol. 66, No. 4, 1982, pp. 539-546; Mary Budd Rowe, "Why Don't Blacks Pick Science?" ***The Science Teacher,*** vol. 44, 1977, pp. 34-35. Lee, op. cit., footnote 9. Data from the most recent National Assessment of Educational Progress show that 48 percent of Blacks in grade three said that they would like to work at a job using mathematics v. 38 percent of white students. Students in grades 7 and 11 were asked a different question, whether they expected to work in an area that requires mathematics. In grade 7, 46 percent of whites and 39 percent of Blacks said yes and in grade 11, 45 percent of whites and 51 percent of Blacks said yes. See Dossey et al., op. cit., footnote 27, pp. 95-100.

service or become convinced that even a college degree is no guarantee of a good job."

Schools, school districts, and States need to do much more to help minorities gain access to science and engineering careers. Teachers need to be sensitized to minority concerns and to involve all students in mathematics and science experiences, such as laboratory experiments. Schools need to develop better guidance counseling, and inculcate higher expectations for minorities among counselors, teachers, and students. Schools and school districts also need to improve their course offerings and ensure that all students have access to the preparatory courses leading to a science and engineering degree. And States and school districts need to ensure that schools with high minority populations receive a fair share of financial, teaching, and equipment resources, given that such schools are often in poor areas.[33]

Undertaking such reforms will be difficult for an education system that changes very slowly. In any event, such actions still will not overcome wider societal pressures that minorities believe deter them from science and engineering careers. Specific intervention programs (discussed in ch. 5) are needed to overcome these deterrents.

[32] Signithia Fordham, "Recklessness as a Factor in Black Student's School Success: Pragmatic Strategy or Pyrrhic Victory," *Harvard Educational Review, vol. 58, No.* 1, February 1988, pp. 54-84; *ERIC/SMEAC Information Bulletin,* "A Review of the Literature on Blacks and Mathematics," No. 1, 1985.

[33] A veritable flood of successful interventions with minority students, in schools and out, is detailed in Lisbeth B. Schorr, *Within Our Reach: Breaking the Cycle of Disadvantage (New* York, NY: Anchor Press Doubleday, 1988), especially chs. 8-12.

## SCHOOLS AS TALENT SCOUTS

The goals of excellence and equity both depend on taking full advantage of the Nation's talent. Doing so depends on having schools act in large measure as talent scouts. Instead, the schools have often acted as curricular traffic cops, encouraging the obviously talented, and culling out those who do not display the conventional signs of ability and drive at an early age. Too many students "never play the game" of science. (See box l-A. ) The result is a waste of talent.

Similar wastes of nonscientific talent undoubtedly take place. The importance of high school preparation in science and mathematics to future success in these careers, though, makes waste particularly serious in these fields. In the future, schools will need to cast their nets wider in identifying potential scientists and engineers, going beyond the standard model of talent. The growing ethnic and cultural diversity of young Americans makes this task both more challenging and more important. The remainder of this report will detail the steps schools and communities might take to meet this national need.

**Box l-A.—Never Playing the Game**

Learning science—its theories, its parameters, its context-can be likened to learning all the rules of a sport-the facilities needed for playing, the scoring, the timing, the uniforms. To prepare to play, one must develop physical skills by means of strenuous exercise and conditioning. Such skill development can span great time periods and demand much energy, commitment, and sacrifice. But, most potential players are willing to devote whatever time and work are needed to succeed, because once they reach the playing field, their effort will be rewarded.

In typical science teaching, we ignore the lessons we might learn from sports. We pronounce science a fantastic game—that all should learn to play it. We spend years teaching background material, laws, rules, classification schemes, and verifications (disciplines) of the basic game. We plan activities for our students designed to develop in them specific skills that the best scientists seem to possess and use. We believe that proficiency with these skills is an important part of an education in science. It is as if we were developing conditioning exercises to train our students for the science they may actually do at a future time.

Unfortunately, however, our students rarely get to play—rarely get to do real science, to investigate a problem that they have identified, to formulate possible explanations, to devise tests for individual explanations. Instead, school science means 13 years of learning the rules of the game, practicing verification-type labs, learning the accepted explanations developed by others, and the special vocabulary and the procedures others have devised and used.

If potential athletes had to wait 13 years before playing a single scrimmage, a single set, a single quarter, how many would be clamoring to be involved? How many would do the pull-ups and the sit-ups? How many would learn the rues if there were no rewards-until college—for those who had practiced enough to play?

We expect much in science education! Could one of our problems be too much promise of what science is really like at a date much too far removed from the rigor and practice science demands? Thirteen years of preparation is a long time to wait before finding out whether a sport (or career) is as satisfying as one's parents and teachers suggest it will be.

To prepare for the game of science for 13 years without even an opportunity to play is a problem{ Like athletes, science students may need to play the game frequently, to use the information and skills they possess, and to encounter a real need for more background and more skills. Such an entree to real science in school could result in more students wanting to know and wanting to practice the necessary skills. Now, we lose too many students with only the promise that the background information and skills we require them to practice will be useful.

Paul Brandwein asserts that most students never have a single experience with real science throughout their whole schooling. He has written that we would have a revolution on our hands if every student had but one experience with real science each year he or she is in school. Are we ready for such a revolution? Can we afford not to clamor for it?

To spend 13 years preparing for a game, but never once to play it, is too much for anyone. Teachers and students alike are more motivated when they experience real questions, follow up on real curiosity, and experience the thrill of creating explanations and the fun of testing their own ideas. Real science must become a central focus in the courses we call science-across the entire K-12 curriculum.

SOURCE: Quoted from Robert E. Yager, "Never Playing the Game," The *Science Teacher*, September 19SS, p. 77.