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## Scientific Illiteracy: Causes, Costs and Cures

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## Scientific Illiteracy: Causes, Costs and Cures

### Abstract

[Excerpt] This article examines the causes of the learning deficits in science, math and technology, evaluates their social costs and then recommends policy measures for remedying the problems identified. Following the American Association for the Advancement of Science's Science for All Americans report, I define the domain of "science" very broadly to include mathematics and technology along with the natural sciences. To avoid confusing readers accustomed to the narrower definition of science, broadly defined science is referred to as science, mathematics and technology.

### Keywords

CAHRS, ILR, center, human resource, job, worker, advanced, labor market, satisfaction, employee, work, manage, American, student, performance, employment, school, role, employ, vocational, education, United States, youth, risk, work, job, training, occupation, college, examination, school, student, learning, economic

### Comments

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**SCIENTIFIC ILLITERACY:  
CAUSES, COSTS AND CURES**

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Working Paper # 89-12

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607-255-2742

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6/13/89

## SCIENTIFIC ILLITERACY: CAUSES, COSTS AND CURES

The scientific, mathematical and technical competence of American high school students is generally recognized to be very low. The National Assessment of Educational Progress (NAEP) reports that only 7.5 percent of 17 year old students can "integrate specialized scientific information" (NAEP 1988 p.51) and 6.4 percent "demonstrated the capacity to apply mathematical operations in a variety of problem settings." (NAEP 1988b p. 42)

There is a large gap between the science and math competence of young Americans and their counterparts overseas. In the 1960s, the low ranking of American high school students in such comparisons was attributed to the fact that the test was administered to a larger proportion of American than European and Japanese youth. This is no longer the case. Figures 1 to 4 plot the scores in Algebra, Biology, Chemistry and Physics against proportion of the 18-year old population in the types of courses to which the international test was administered. In the Second International Math Study, the universe from which the American sample was drawn consisted of high school seniors taking a college preparatory math course. This group represents 13 percent of the age cohort, a proportion that is roughly comparable to the 12 percent of Japanese youth who were in their sample frame and is considerably smaller than the 19 percent of youth in the Canadian province of Ontario and the 50 percent of Hungarians who took the test. In Algebra, the mean score for this very select group of American students was about equal to the mean score of the much larger group of Hungarians and substantially below the Canadian achievement level (McKnight et al 1987).

The findings of the Second International Science Study are even more dismal. For example, the 25 % of Canadian 18-year olds taking chemistry know just as much chemistry as the very select 1 % of Americans high school seniors taking their second chemistry course (most of whom are in "Advanced Placement"). The 28 % taking biology know much more than the 6 % of American 17-18 year olds who are taking their second biology course (International Association for the Evaluation of Educational Achievement, 1988).

(Figure 1-4 about here)

The poor performance of American students is sometimes blamed on the nation's "diversity". Many affluent parents apparently believe that their children are doing acceptably by international standards. This is not the case. In Stevenson, Lee and Stigler's (1986) study

FIGURE 1

# ALGEBRA RESULTS FOR 17-YEAR-OLDS

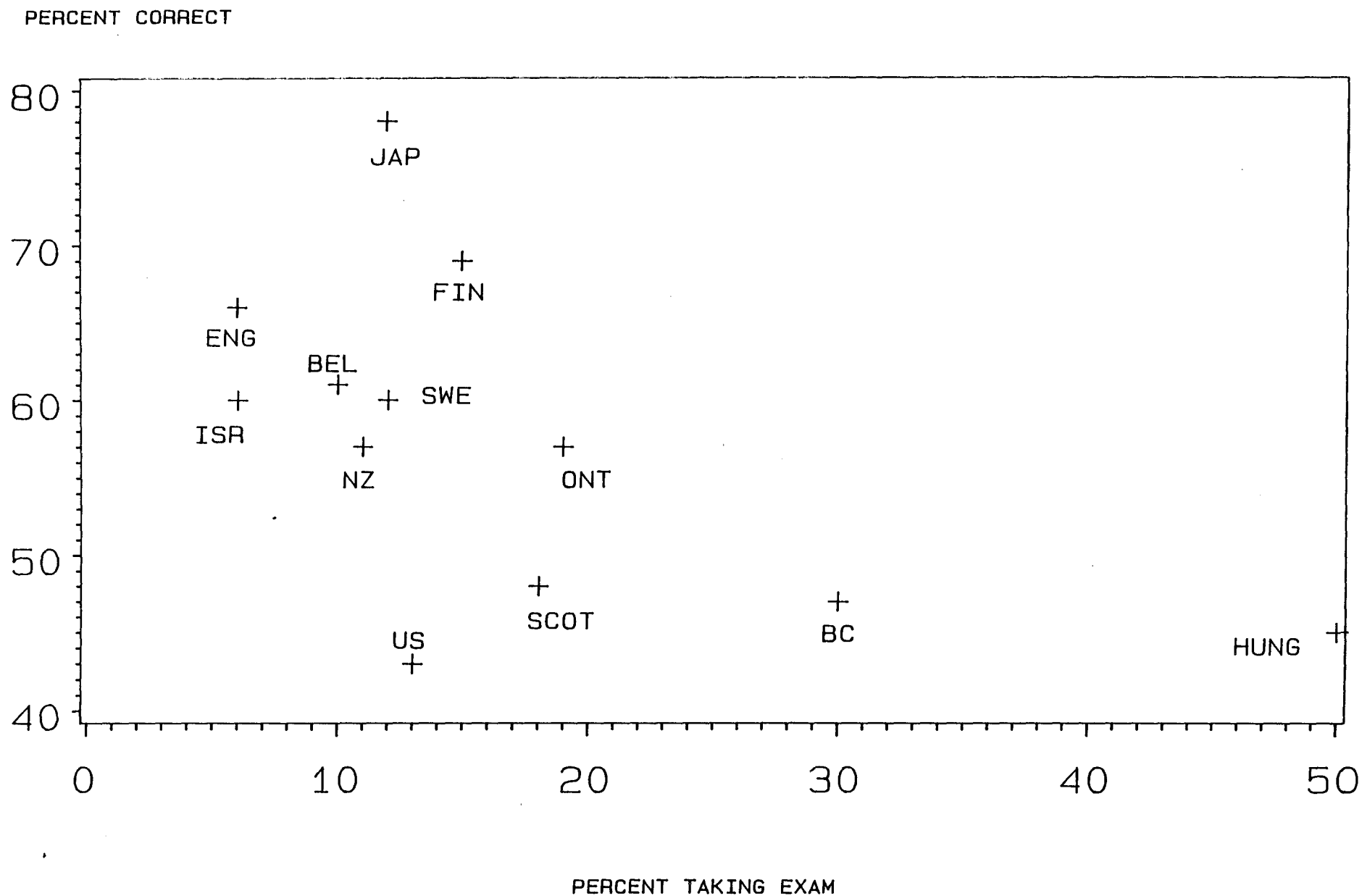


FIGURE 2

# BIOLOGY RESULTS FOR 18-YEAR-OLDS

STANDARD DEVIATION UNITS

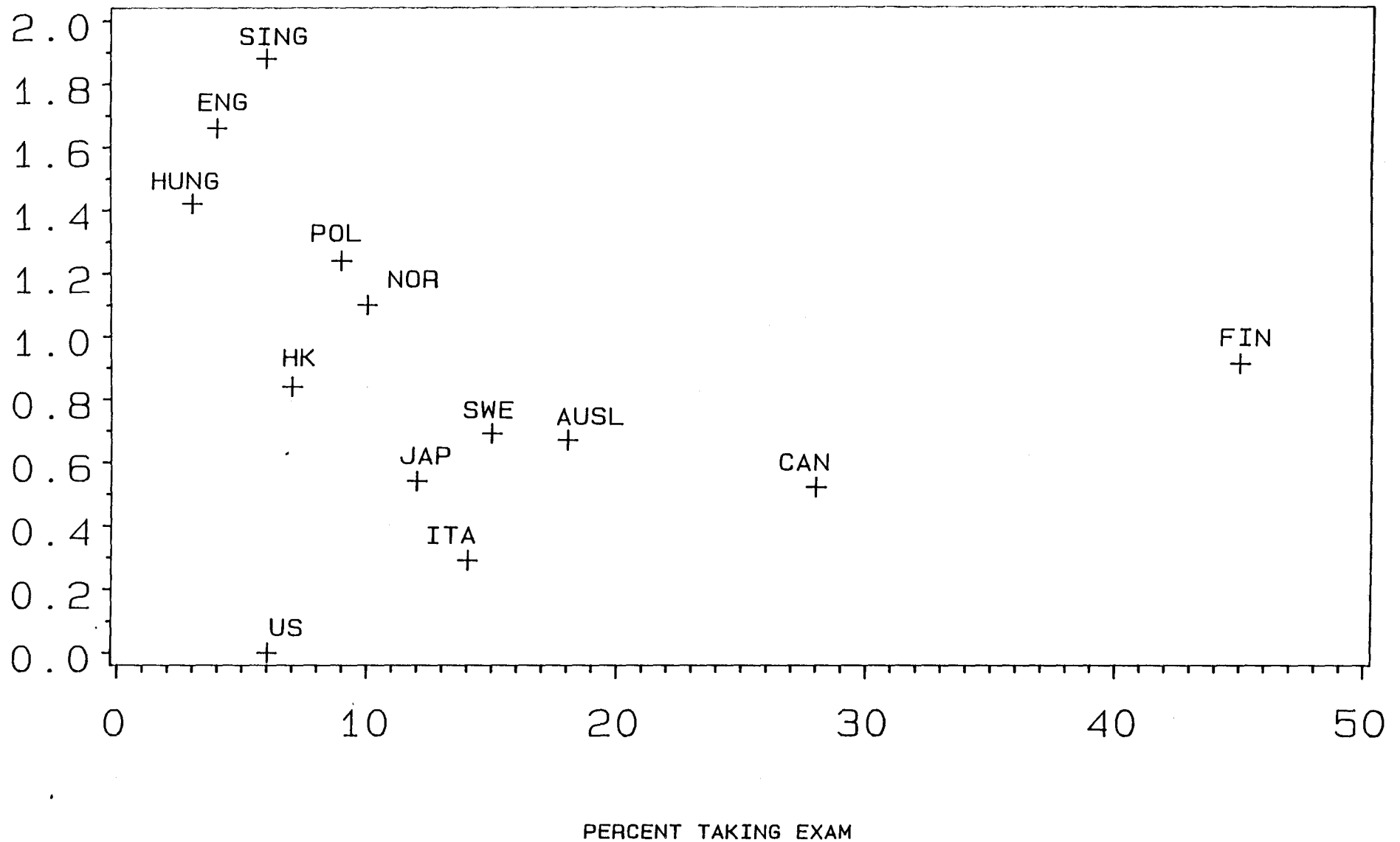
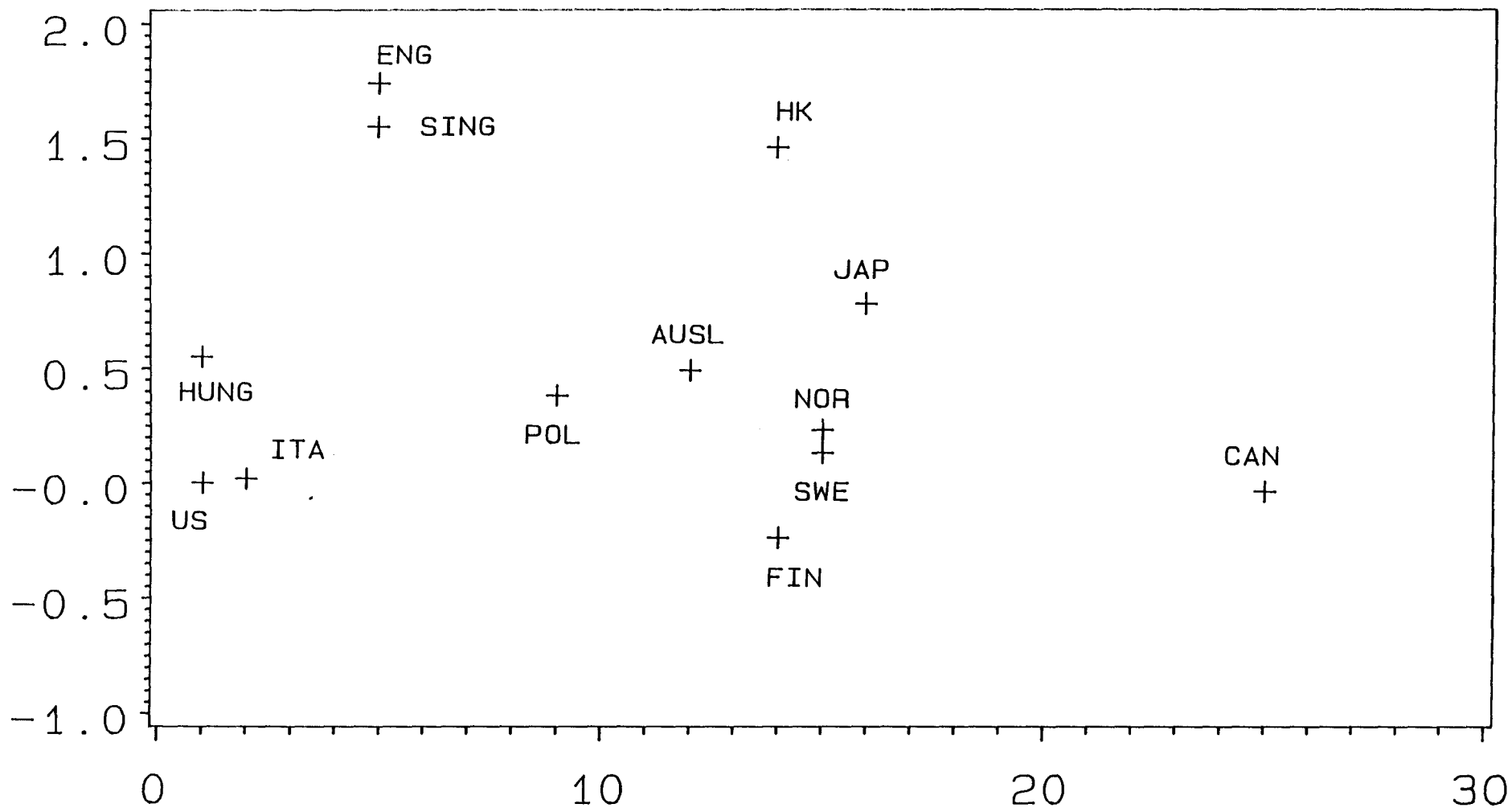


FIGURE 3

# CHEMISTRY RESULTS FOR 18-YEAR-OLDS

STANDARD DEVIATION UNITS

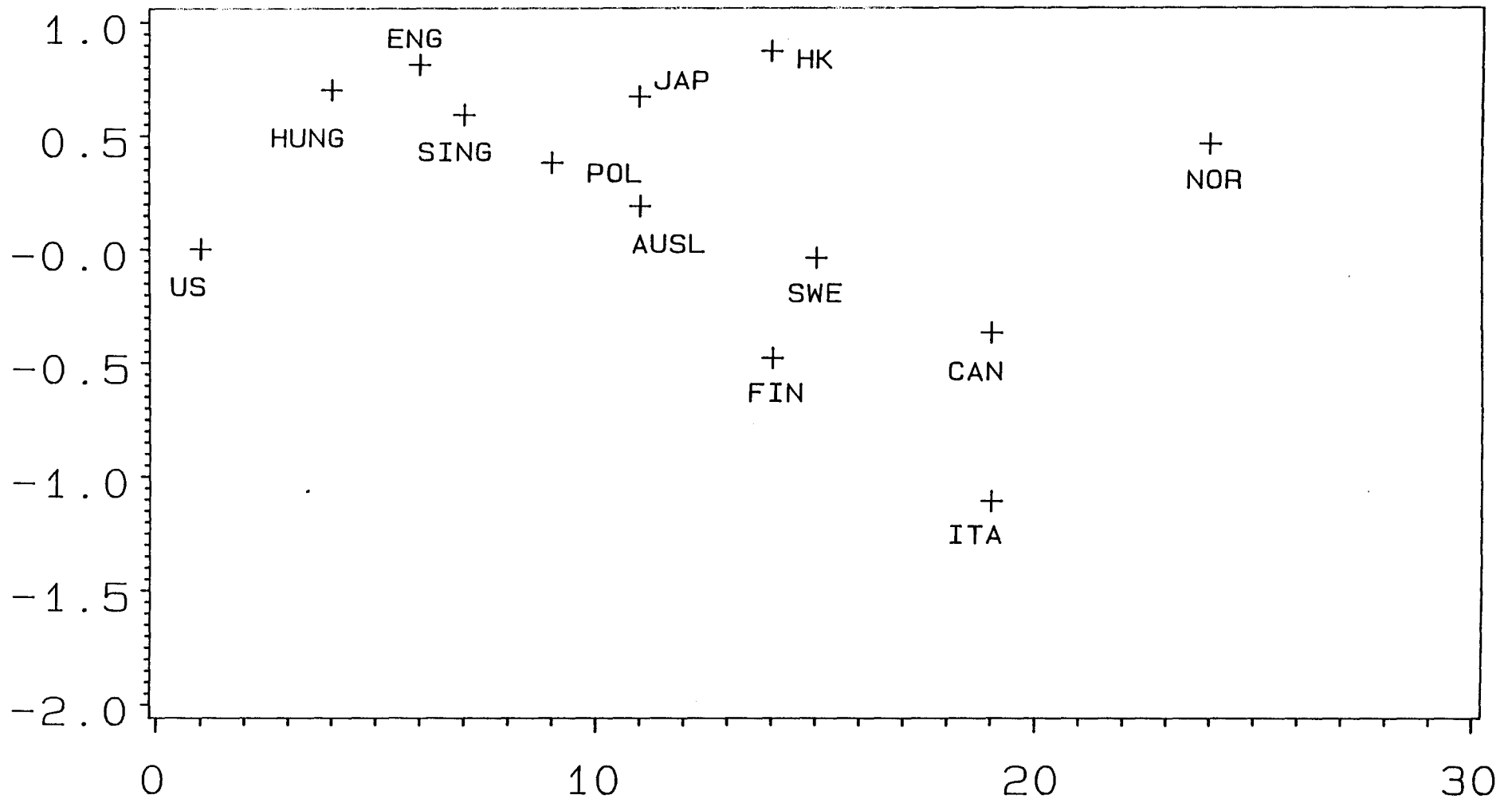


PERCENT TAKING EXAM

FIGURE 4

# PHYSICS RESULTS FOR 18-YEAR-OLDS

STANDARD DEVIATION UNITS



PERCENT TAKING EXAM



by international standards. This is not the case. In Stevenson, Lee and Stigler's (1986) study of 5th grade math achievement, the best of the 20 classrooms sampled in Minneapolis was outstripped by every single classroom studied in Sendai, Japan and by 19 of the 20 classrooms studied in Taipeh, Taiwan. The nation's top high school students rank far behind much less elite samples of students in other countries. At the end of secondary school the gaps in science between white American students and their counterparts in England, Canada, Finland and Japan are as large as the black-white gap in the US and in mathematics the gaps are more than twice as large as the black-white gap. The learning deficit is pervasive.

This article examines the causes of the learning deficits in science, math and technology, evaluates their social costs and then recommends policy measures for remedying the problems identified. Following the American Association for the Advancement of Science's Science for All Americans report, I define the domain of "science" very broadly to include mathematics and technology along with the natural sciences. To avoid confusing readers accustomed to the narrower definition of science, broadly defined science is referred to as science, mathematics and technology.

The paper is organized as follows. Section 1 presents evidence that American students devote considerably less time and energy to studying science, math and technology in high school than their counterparts abroad. Section 2 attributes the apathy of students and parents regarding science, math and technology education to the failure of our society to recognize and reward students who commit the time and energy necessary to master these subjects. Competence in science has **absolutely no** effect on the wages or earnings of people under the age of 30 and very little effect on their chances of admission to more prestigious colleges. Competence in mathematical reasoning has **no** effects on the labor market success of young men and **only very limited** effects on the labor market success of young women. Competence in the technological arena, by contrast, has **very substantial positive** effects on the wages and earnings of young males.

Section 3 examines the social costs of the learning deficits in science, math and technology. Mathematical and technological competencies are found to have substantial effects on hands-on measures of job performance in military jobs which are similar to the blue collar and technical jobs occupied by the majority of male high school graduates. Competence in mathematical reasoning has substantial effects on job performance in clerical jobs. Science

knowledge has modest effects on job performance in both types of jobs. This implies that even though the labor market fails to reward most young people who have studied and learned science and mathematics, the nation's future productivity will be enhanced if high school students receive a stronger mathematics and science background, though the effect of science knowledge is not as large as one might hope. For young men and women hoping to obtain blue collar and technical jobs, the empirical analysis suggests that technological competence is a powerful contributor to both productivity and labor market success. The Nation at Risk report recommendation that all students take a course in computers gave some recognition to the need for technology education but computers are only one of technologies we interact with on a daily basis. This is an area of study that needs much more attention than it has been getting. Section 4 sets forth a series of policy recommendations designed to improve student incentives to devote time and energy to learning and to strengthen parental incentives to demand that local schools be upgraded.

## **I. APATHY: THE PROXIMATE CAUSE OF THE SCIENCE LEARNING DEFICIT**

American high school students do poorly in these international comparisons primarily because they devote a lot less time and energy to the task of learning. American students average nearly 20 absences a year; Japanese students only 3 a year (Berlin and Sum 1988). School years are longer in Europe and Japan. Thomas Rohlen has estimated that Japanese high school graduates average the equivalent of three more years in a classroom and studying than American graduates. Studies of time use and time-on-task show that American students actively engage in a learning activity for only about half the time they are in school. A study of schools in Chicago found that public schools with high-achieving students averaged about 75 % of class time for actual instruction; for schools with low achieving students, the average was 51 % of class time (Frederick, 1977). Overall, Frederick, Walberg and Rasher (1979) estimated 46.5 percent of the potential learning time was lost due to absence, lateness, and inattention.

In the High School and Beyond Survey students reported spending an average of 3.5 hours per week on homework. When homework is added to engaged time at school, the total time devoted to study, instruction, and practice is only 18-22 hours per week -- between 15 and 20 % of the student's waking hours during the school year. By way of comparison, the

watching television (A. C. Neilsen unpublished data). Thus, TV occupies as much time as learning. Students in other nations spend much less time watching TV: 55% less in Finland, 70% less in Norway and 44% less in Canada (Organization of Economic Cooperation and Development, Table 18.1, 1986). Science and mathematics deficits are particularly severe because most students do not take rigorous college preparatory courses in these subjects. The high school graduating class of 1982 took an average of only .43 credits of Algebra II, .31 credits of more advanced mathematics courses, .40 credits of chemistry and .19 credits of physics (Meyer 1988 Table A.2).

Even more important than the time devoted to learning is the intensity of the student's involvement in the process. At the completion of his study of American high schools, TheodoreSizer (1984) characterized students as, **"All too often docile, compliant, and without initiative (p. 54)"**. John Goodlad (1983) described: **"a general picture of considerable passivity among students...(p. 113)"**. Sixty-two percent of 10th graders agree with the statement, "I don't like to do any more school work than I have to" (Longitudinal Survey of American Youth or LSAY, Q. AA37N). The high school teachers surveyed by Goodlad ranked "lack of student interest" and "lack of parental interest" as the two most important problems in education.

The student's lack of interest makes it difficult for teachers to be demanding. Sizer's description of Ms. Shiffe's class, illustrates what sometimes happens:

Even while the names of living things poured out of Shiffe's lecture, no one was taking notes. She wanted the students to know these names. They did not want to know them and were not going to learn them. Apparently no outside threat--flunking, for example--affected the students. Shiffe did her thing, the students chattered on, even in the presence of a visitor....Their common front of uninterest probably made examinations moot. Shiffe could not flunk them all, and, if their performance was uniformly shoddy, she would have to pass them all. Her desperation was as obvious as the students cruelty toward her."(p. 157-158)

Some teachers are able to overcome the obstacles and induce their students to undertake tough learning tasks. But for most, the student's lassitude is demoralizing. Teachers are assigned responsibility for setting high standards but we do not give them any of the tools that might be effective for inducing student observance of the academic goals of the classroom. They finally must rely on the force of their own personalities. All too often

teachers compromise academic demands because the bulk of the class sees no need to accept them as reasonable and legitimate.

### The Apathy of Parents and School Boards

The second major reason for the low levels of science and math achievement is parental and school board apathy. An NSF funded survey of 2222 parents of 10th graders found that 25 percent thought their child should take only 1 or 2 science classes in high school (LSAY, Q. BH165). When 2829 high school sophomores were asked whether "My parents...think that math (science) is a very important subject," 40 percent said no with respect to math and 57 percent said no for science (LSAY, Q. AA19Q-AA19R). Only 30 percent of 10th graders reported their parents "want me to learn about computers" (LSAY, Q. AA19D).

Japanese families allocate 10 percent of the family's income to educational expenses; American families only 2 percent. If American parents were truly dissatisfied with the performance of their local public schools, they would send their children to tuition financed schools offering an enriched and rigorous curriculum (as so many Australian parents do) or arrange for their children to receive tutoring help (as half of Japanese parents do). Private investment in secondary education is relatively low in the US because parents are satisfied with the education their children are getting at the public schools.

A comparative study of primary education in Taiwan, Japan and United States found that **even though American children are far behind Taiwanese and Japanese children in mathematics capability, American mothers are much more pleased with the performance of their local schools than Taiwanese and Japanese mothers.** When asked "How good a job would you say \_\_\_'s school is doing this year educating\_\_\_", 91 percent of American mothers responded "excellent" or "good" while only 42 percent of Taiwanese and 39 percent of Japanese parents were this positive (Stevenson 1983). Clearly, American parents hold their children and their schools to lower academic standards than Japanese and Taiwanese--as well as European -- parents. Why is this the case?

## II. INCENTIVES: THE REAL CAUSE OF THE SCIENCE LEARNING DEFICIT

### Incentives for Learning Science in High School

The fundamental cause of student and parental apathy regarding science, mathematics and technology education is the absence of good signals of learning in high school and a consequent lack of rewards for learning science and mathematics. The signals of learning generated by our educational system such as years of schooling and SAT scores generate handsome rewards--better paying jobs and admission to prestigious colleges. Science and technological learning accomplishments in high school are by contrast poorly signaled to colleges. Science and mathematics learning accomplishments are poorly signaled to employers. Learning accomplishments not signaled are not rewarded. The lack of incentives for learning in science, math and technology are a consequence of three phenomena:

- \* The peer group actively discourages academic effort.
- \* Admission to selective colleges is not significantly influenced by achievement in science and technology. It is based instead on aptitude tests which do not assess competence in science and on class rank and grade point averages, which are defined relative to classmates' performances not relative to an external standard.
- \* The labor market does not reward science and math achievement in high school.

### The Zero-Sum Nature of Academic Competition in High School

An important cause of high school students' poor motivation is peer pressure against studying hard. Students who enjoy science and work hard in science courses are considered "nerds" by most of their classmates. The primary reason for peer pressure against studying hard is that pursuing academic success forces students into a zero-sum competition with their classmates. Their achievement is not being measured against an absolute, external standard. In contrast to scout merit badges, for example, where recognition is given for achieving a fixed standard of competence, the schools' measures of achievement assess performance relative to fellow students through grades and class rank. When students try hard to excel, they set themselves apart, cause rivalries and may make things worse for friends. When we set up a zero sum competition among close friends, we should not be surprised when they decide not to compete. All work groups have ways of sanctioning "rate busters." High school students call them "brain geeks," "grade grubbers," and "brown nosers."

The second reason for peer norms against studying is that most students perceive the chance of receiving recognition for an academic achievement to be so slim they have given up trying. At most high school awards ceremonies, the academic recognition goes to only a few--those at the very top of the class. By 9th grade, most students are already so far behind the leaders, that they know they have no chance of being perceived as academically successful. Their reaction is often to dismiss the students who take learning seriously and to honor other forms of achievement--athletics, dating, holding their liquor, and being "cool"--which offer them better chances of success.

### College Selection Criteria

In Canada, Australia, Japan, and Europe, educational systems administer achievement exams in science, mathematics and other subjects which are closely tied to the curriculum. With the exception of Japan, all of these exams use an extended answer format. Performance on these exams is the primary determinant of admission to a university and to a field of study and good grades on the toughest exams--physics, chemistry, advanced mathematics--carry particular weight. In the United States, by contrast, the national tests which influence college admission decisions--the SAT and the ACT--are multiple choice exams that do not assess the student's knowledge and understanding of science and technology.<sup>1</sup> The American exams that are similar to those administered in Canada, Australia and Europe--the Advanced Placement exams--are taken by only 6.6 percent of high school seniors and have little impact on college admission decisions.

High school grade point averages and class rankings have substantial effects on who is admitted to the most prestigious colleges. Since most classes are graded on a curve, **taking more rigorous science and math courses lowers the student's grade point average.**<sup>2</sup> Many college admission officers try to factor course difficulty into their evaluations, but most high school students still believe that A's in regular classes are better than B's in honors classes. The result is that many students avoid taking the more demanding courses such as chemistry, physics and calculus. The second problem with the use of GPA and class rank as college admission criteria is that it results in zero-sum competition between classmates and consequently contributes to peer pressure against studying and parental apathy about the quality of teaching and the rigor of the curriculum.

### **The Absence of Major Economic Rewards for Effort in High School**

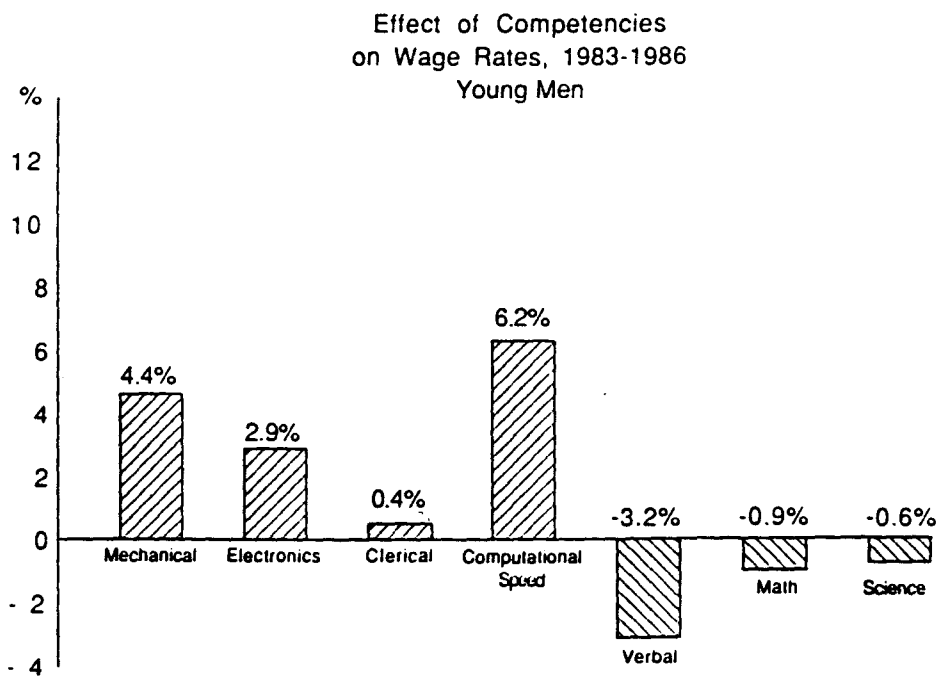
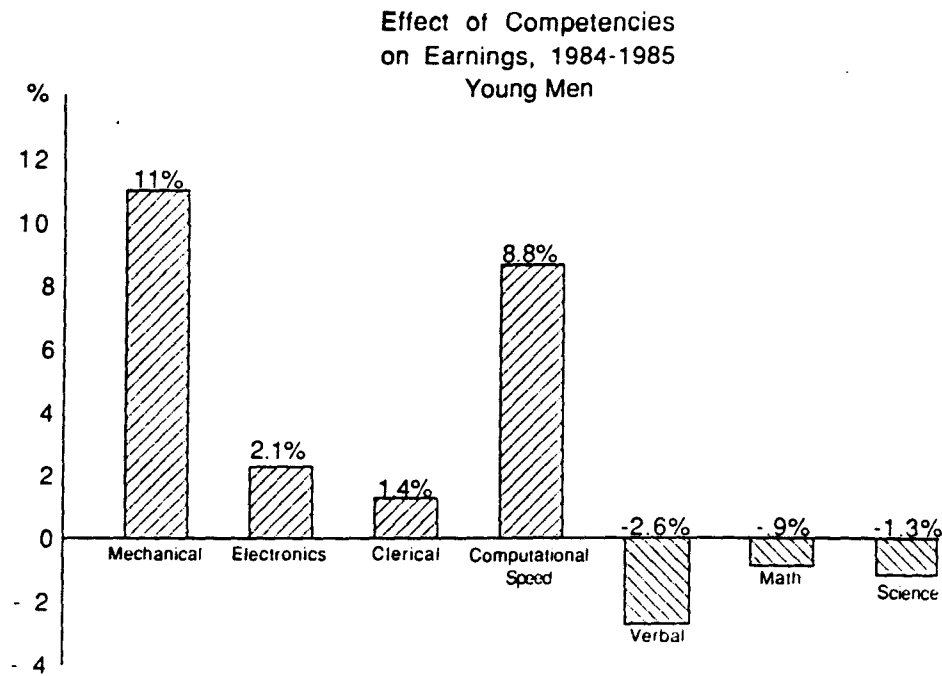
Students who plan to look for a job immediately after high school typically spend considerably less time studying science and mathematics than those who plan to attend college. In large part, most see very little connection between how much they learn and their future success in the labor market. When 10th graders are asked "Which of the following math [and science] courses will you need to qualify for your first choice of job," only 23 percent check geometry, 29 percent check algebra, 18 percent check trigonometry, and only 20-21 percent check biology, chemistry and physics (Longitudinal Survey of American Youth 1988, Quest. BA24B-BA25D). Statistical studies of the youth labor market confirm their skepticism about the benefits of taking tough math and science courses and studying hard.

A study of 1972 high school graduates by Joseph Altonji (1988) for the National Center for Education and Employment found that when family background and years of schooling are controlled, the number of science courses taken in high school had no effect on wage rates in the first 14 years after graduating from high school. Science courses were associated with higher rates of wage growth, however, so there may be more substantial benefits coming when the individuals reach the age of 40. By contrast, both math courses and industrial, trade and technical courses had significant positive effects. The effect of two additional full year math courses on wage rates was between .88 percent and 3.4 percent depending on specification. One full year course in an applied technology field raised wage rates by 2.5-2.8 percent.

[Figure 5 and 6 about here]

Results of an analysis of the ability of subtest scores of the Armed Service Vocational Aptitude Test Battery (sample questions for each sub-test are provided in Appendix A) to predict the labor market success of men and women in the Youth Cohort of the National Longitudinal Survey are summarized in figures 5 and 6 (Bishop, 1988b). It was found that, holding years of completed schooling and college attendance constant, that young men received no rewards from the labor market for developing competence in science, language arts and mathematical reasoning during the first 8 years after leaving high school. The only competencies that were rewarded were speed in doing simple computations (something that calculators do better than people) and technical competence (knowledge of mechanical principles, electronics, automobiles and shop tools). For the non-college bound female, there

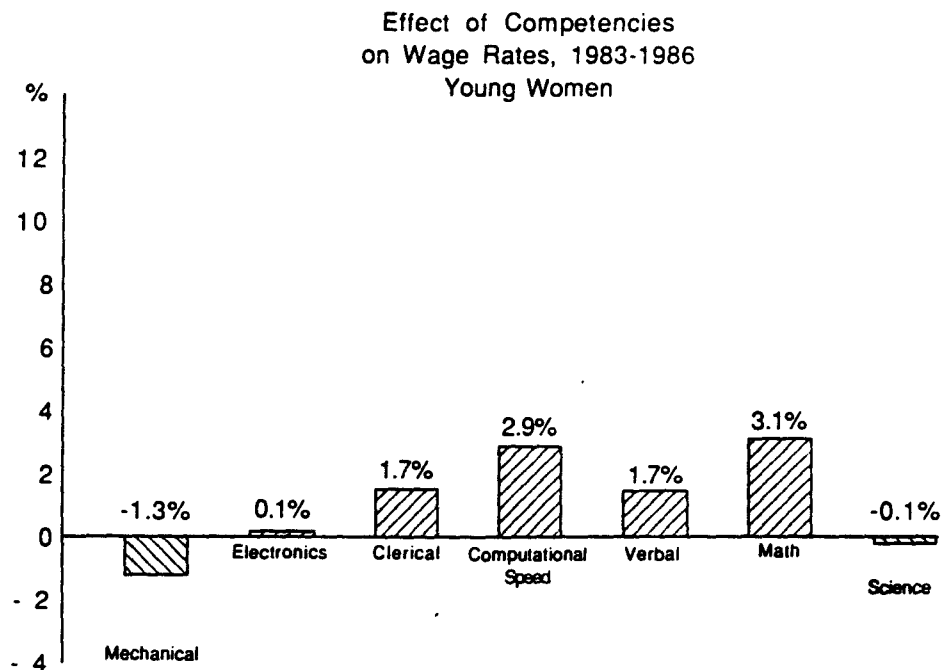
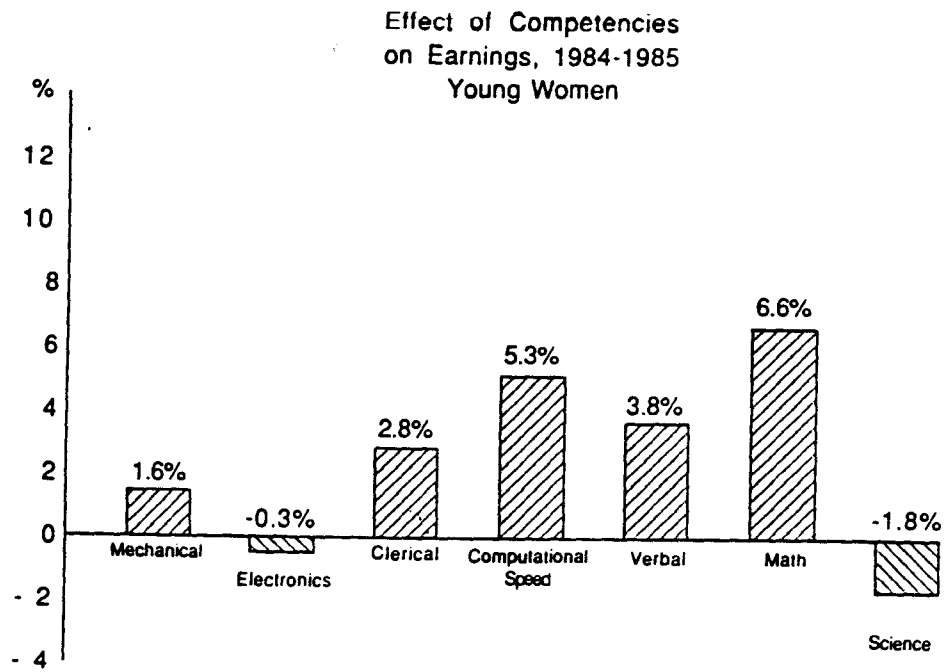
Figure 5



Source: Analysis of NLS Youth data. The figure reports the effect of a one population standard deviation increase in Armed Services Vocational Aptitude Battery subtest while controlling for schooling, school attendance, age, work experience, region, SMSA residence and ethnicity.



Figure 6



Source: Analysis of NLS Youth data. The figure reports the effect of a one population standard deviation increase in Armed Services Vocational Aptitude Battery subtest while controlling for schooling, school attendance, age, work experience, region, SMSA residence and ethnicity.

were both wage rate and earnings benefits to learning advanced mathematics but no benefits to developing competence in science or the technical arena. Competence in language arts did not raise wage rates but it did reduce the incidence of unemployment. The payoff to verbal, scientific and mathematical reasoning competencies did not appear to rise with age or labor market experience.<sup>3</sup>

The absence of rewards for science and math learning achievements is due in large part to the lack of objective information available to employers on the learning accomplishments of recent high school graduates. Tests are available for measuring competency in reading, writing, mathematics, science, and problem solving, but EEOC guidelines resulted in a drastic reduction in their use after 1971 (Friedman and Williams 1982). A 1987 survey of a stratified random sample of small-and medium-sized employers who were members of the National Federation of Independent Business [NFIB] found that aptitude test scores had been obtained in only 2.9 % of the hiring decisions studied.<sup>4</sup>

Other potential sources of information on learning achievements are referrals from teachers who know the applicant and high school transcripts. Both are under-used. In the NFIB survey, only 5.2 percent of the high school graduates hired had been referred or recommended by vocational teachers and only 2.7 percent had been recommended by someone else in the high school. Transcripts had been obtained prior to the selection decision for only 14.2 percent of the high school graduates hired. If a student or graduate has given written permission for a transcript to be sent to an employer, the Buckley amendment obligates the school to respond. Many high schools are not, however, responding to such requests. The experience of Nationwide Insurance, headquartered in Columbus Ohio, is probably representative. The company obtains permission to get high school records from all young people who interview for a job. It sent over 1,200 signed requests to high schools in 1982 and received only 93 responses. Clearly, hiring selections and starting wage rates often do not reflect the competencies and abilities students have developed in school.

The situation is very different in Europe and Japan. Grades on school leaving exams are requested on job applications and typically included on one's resume. Exhibit 1 reproduces a resume used by Irish secondary school graduate applying for a clerical job. Exhibit 2 is an application form for a clerical job in the United Kingdom. Exhibit 3 is an application filed by a 33 year old university dropout seeking a managerial job. While

## Exhibit 1

Name ;

Address ;

Date of Birth ;

Place of Birth ;

Nationality ;

Marital Status ;

Occupation ;

Father's name ;

Occupation ;

## EDUCATION :

August 1980 - June 1985.

( All five years were spent learning through Irish. )

U.C.D.

## QUALIFICATIONS :

Subject:	Intermediate Cert.	Leaving Cert.
	( June 1983 )	( June 1985 )
Irish	C (H)	C (H)
English	D (H)	C (H)
Mathematics	B (H)	A (P)
French	D	C (P)
German	D	---
Science	A	---
Chemistry	---	C (H)
Physics	---	C (H)
History	B	C (H)
Geography	B	---

# Tarmac

**CONFIDENTIAL**

POSITION APPLIED FOR	RETURN TO
Surname	Permanent Address
Forename(s)	
Date of Birth	
Place of Birth	
Nationality	Telephone No.
Marital Status	Next of Kin
No. of Children	Relationship
Sex and Year of Birth of Children (under 18 yrs)	Address
Do you own a car or motorcycle?	Do you hold a current driving licence?

Please state any serious illness, disability, allergy or operation.....

Are you registered as disabled?..... If yes, state number.....

[illegible][illegible]



3319

Appointment applied for DISTRIBUTION PROJECTS MANAGER (B&Q) Ref.No. ....

PERSONAL DETAILS: (block capitals)

Surname JOHN Title MR Forenames MERVYN JOHN

Address 7, CAERNARVAN GARDENS

Postal Code B15 2AA Tel.No.Home 2 44 33 Work 2 7 66

Marital Status M Children/Dependants (with ages) 1 x 4 YRS, 1 x 1 YR

Age 33 Date of Birth 5.8.55 Nationality BRITISH Place of Birth ILFRACOMBE, DEVON

State of health OK Height 6' Weight 13st. 12lbs

Any disabilities/recurrent medical problems? ..... Regd.disabled .....

Driving Licences CAR Car Owner ✓ Company Car .....

Endorsements, convictions, accidents, etc. .... NONE

Leisure activities and offices held in clubs and societies CYCLING/WALKING

EDUCATION:

Secondary Education

From	To	School	Exams Taken (inc. grades)	Other achievements
1966	1972	BARNSTAPLE GRAMMAR	'O' LEVEL:- ENG. LANG.(2), MATHS(2), PHYSICS(2), GEOGRAPHY(3), STATISTICS(3), CHEMISTRY(3), ADDL. MATHS(6), HISTORY(6), PHYSICS(6) 'A' LEVEL:- CHEMISTRY(E), PHYSICS(E), MATHS(O)	MIDDLE SCHOOL GAMES CAPTAIN

Further Education

From	To	College/University	Course & results (inc.class/grades)	Other achievements
1972	1973	UNIVERSITY OF BRADFORD	APPLIED CHEMISTRY - LEFT AFTER 1 YEAR - DOMESTIC REASONS	

Other training and qualifications (inc. in-company and external courses, etc.)

From	To	Establishment	Training/Qualifications
1979		FARLEY COLLEGE, LEEDS	CERTIFICATE OF PROFESSIONAL COMPETENCE (TRANSPORT OPS)
1983	1984	BRADFORD COLLEGE	INSTITUTE OF INDUSTRIAL MANAGEMENT CERT.
1984	1989	IN-COMPANY	NUMEROUS MANAGEMENT COURSES.

Membership of professional bodies

Date	Association/Institute	Grade of membership	Offices held
1988	I.P.D.M.	A.M.	

employers report they pay less attention to exam grades when hiring workers who have been out of school for many years, it is nevertheless significant that the information remains on one's resume long after graduation from high school. In Japan, clerical, service and blue collar jobs at the best firms are available only to those recommended by their high school. The most prestigious firms have long term arrangements with particular high schools to which they essentially delegate the responsibility of selecting the new hire(s) for the firm. The criteria by which the high school is to make its selection is, by mutual agreement, grades and exam results (Rosenbaum and Kariya 1987).

Because information on school performance is available to employers, recent secondary school graduates in these countries are hired into primary labor market jobs that offer considerable training and access to career ladders at high paying firms. In the United States recent high school graduates are never even considered for these high quality jobs.

### **Incentives to Upgrade Local Schools**

The lack of external standards for judging learning achievement in science, the resulting zero sum nature of academic competition in the school and the lack of economic rewards for science learning also influences parents, school boards, and local school administrators. Parents can see that higher standards in science classes or hiring better science teachers will not on average improve their child's rank in class or GPA. Improving the teaching of science at the local high school will have only minor effects on how my child does on the SAT, so why worry about standards? Scores on AP exams and other achievement tests have little effect on admission to better colleges.

The parents of children not planning to go to college have an even weaker incentive to demand high standards at the local high school. They believe that what counts in the labor market is getting the diploma, not learning chemistry. They can see that learning more will be of only modest benefit to their child's future, and that higher standards might put at risk what is really important--the diploma.

In our system, locally elected school boards and the administrative and teaching staff hired by these boards make the decisions--teacher salaries, teacher hiring selections, availability of AP courses, grading standards, homework assignments--which determine the quality of education in local schools. If substantial grassroots pressure for higher standards does not

come from parents, state mandates designed to upgrade the quality of instruction will not have a lasting impact.

### III. THE SOCIAL COSTS OF THE LEARNING DEFICIT

Will the deficit in science, mathematics and technology have major consequences for the nation's standard of living? In the view of the National Commission on Excellence in Education, it will:

If only to keep and improve on the slim competitive edge we still retain in world markets, we must dedicate ourselves to the reform of our educational system....Learning is the indispensable investment required for success in the information age we are entering (p 7).

Behind their call for higher standards and more class time devoted to studying math and science is an assumption that most jobs require significant competency in these fields.

At least with respect to science, however, there is controversy about these claims. Morris Shamos, an emeritus professor of physics at New York University, argues that "widespread scientific literacy is not essential to... prepare people for an increasingly technological society" (Education Week, Nov. 23 1988. p. 28). About 24 percent of the high school sophomores who are planning to attend college report they are interested in pursuing a scientific or technical career (Office of Technology Assessment, 1988, Figure 1.1). Shamos does not dispute the need for these students to receive a thorough science education in high school. He argues, however, there is no need for most citizens and workers to become scientifically literate. A similar argument could also be made regarding the necessity of most students taking algebra, geometry, trigonometry and statistics.

At least with respect to workers in non-technical occupations, his view might appear at first glance to be supported by the findings cited above that achievement in science has no effects on wage rates, earnings or unemployment of young men and women when other competencies are held constant. Further support for the Shamos position would appear to come from a survey of small and medium sized employers who are members of the National Federation of Independent Business. When asked how frequently the employee most recently hired by their firm needed to "use knowledge gained of chemistry, physics or biology" in their job, 74 percent reported that such knowledge was never required and only 12 percent reported such knowledge was used at least once a week. Asked how frequently the new employee had

to "use algebra, trigonometry or calculus", 68 percent reported that such skills were never required by the job and only 12 percent reported they were used at least once a week.

The skills used by entry level workers at NFIB firms, however, are not decisive evidence regarding employer needs for three reasons. First, the low levels of scientific and mathematical competence in the work force may have forced companies to put off technological innovations such as statistical process control that require such skills and to simplify the functions that are performed by workers who lack technical training. If better educated workers were available, entry level workers might be given greater responsibility and become more productive. Second, the NFIB sample does not tell us what is happening at large firms and in the jobs occupied by long tenure employees at small firms. The CEOs of many large technologically progressive companies such as Motorola and Xerox are insisting that their factory jobs now require workers who are much better prepared in math and science than ever before. Third, employers may not realize how the knowledge and skills developed in high school science and mathematics classes contribute to productivity in their jobs. Not knowing which employee possesses which academic skill, they would have no way of learning from experience which scientific and mathematical skills are helpful in doing a particular job. Science and mathematics are thought to teach thinking, reasoning and learning skills applicable outside the classroom and the laboratory. If these skills are indeed successfully developed by these courses, productivity might benefit even when there are no visible connections between job tasks and course content.

The lack of wage and earnings responses to scientific and mathematical knowledge is also not decisive evidence in favor of the Shamos position for research indicates that differences in worker productivity do not result in proportional differences in wage rates. When people hired for the same or very similar jobs are compared, someone who is 20 % more productive than average in the first weeks on a job receives only a 1.6 % higher starting wage. After a year at a firm, better producers received only a 4% higher wage at nonunion firms with about 20 employees, and they had no wage advantage at unionized establishments with more than 100 employees or at nonunion establishments with more than 400 employees (Bishop, 1987a).

Employers have good reasons for not varying the wage rates of their employees in proportion to their perceived job performance. All feasible measures of individual productivity



are unreliable and unstable. In most cases only subjective measures of job performance are available. Workers are risk averse and reluctant to accept jobs in which the judgement of one supervisor can result in a large wage decline in the second year on the job (Hashimoto and Yu 1980; Stiglitz 1974). Most productivity differentials are specific to the firm, and this reduces the risk that not paying a particularly productive worker a comparably higher salary will result in him going elsewhere (Bishop, 1987a). Pay that is highly contingent on individual performance can also weaken cooperation and generate incentives to sabotage others (Lazear 1986). Finally, in unionized settings, the union's opposition to merit pay will often be decisive.

If relative wage rates only partially compensate the most capable workers in a job for their greater productivity, why don't they obtain promotions or switch to better paying firms? To some degree they do, particularly in managerial, professional, technical and craft occupations. Since, however, worker productivity cannot be measured accurately and cannot be signaled reliably to other employers, this sorting process is slow and only partially effective. Consequently, when men and women under the age of 30 are studied, the wage rate effects of specific competencies may not correspond to their true effects on productivity and, therefore, direct evidence on productivity effects of specific competencies is required before conclusions may be drawn. We turn, therefore, to direct evidence on the effects of scientific, mathematical and technical competencies on the job performance.

### The Impact of Science, Math and Technical Competency on Worker Productivity

Over the last 70 years, industrial psychologists have conducted hundreds of studies, involving hundreds of thousands of workers, on the relationship between productivity in particular jobs and various predictors of that productivity. They have found that scores on tests measuring competence in reading, arithmetic and mechanical comprehension are strongly related to productivity in almost all of the civilian jobs studied (Ghiselli 1973; Hunter 1983). Published studies of productivity in civilian jobs have, however, generally not examined the effect of competence in science and high school level mathematics (algebra, geometry and trigonometry) on job performance. For military jobs, however, there is a great deal of evidence on the effect of competence in science and high school level mathematics on job performance. The Armed Services Vocational Aptitude Battery contains both a Math Knowledge subtest evaluating competence in algebra and geometry and a General Science

subtest. This science test focuses on science facts and concepts and has minimal coverage of higher level scientific problem solving. The ASVAB also contains 4 subtests which evaluate the individual's technological competence--mechanical comprehension, electronics information, auto information and shop information (sample questions are provided in Appendix A).<sup>5</sup> The research using the ASVAB has found that scientific, technical and mathematical reasoning competencies all have large effects on success in training and on paper and pencil measures of job knowledge (Hunter, Crosson and Friedman 1985).

Since, however, both the criterion--training success--and the predictors--competence in particular areas--are measured by paper and pencil tests, there is a danger that results may be biased by common methods bias. Therefore, it would be desirable to check these findings in a data set in which ASVAB subtest scores predict a hands-on measure of job performance. Maier and Grafton's (1981) study of ASVAB 6/7's ability to predict the hands-on Skill Qualification Test (SQTs) provides such a data set. Maier and Grafton described the hands-on SQTs they used in their study as follows:

SQTs are designed to assess performance of critical job tasks. They are criterion referenced in the sense that test content is based explicitly on job requirements and the meaning of the test scores is established by expert judgment prior to administration of the test rather than on the basis of score distributions obtained from administration. The content of SQTs is a carefully selected sample from the domain of critical tasks in a specialty. Tasks are selected because they are especially critical, such as a particular weapon system, or because there is a known training deficiency. The focus on training deficiencies means that relatively few on the job can perform the tasks, and the pass rate for these tasks therefore is expected to be low. Since only critical tasks in a specialty are included in SQTs, and then only the more difficult tasks tend to be selected for testing, a reasonable inference is that performance on the SQTs should be a useful indicator of proficiency on the entire domain of critical tasks in the specialty. (p. 4-5)

Correlation matrices relating the ASVAB subtests and SQTs were taken from Appendices A and B in Maier and Grafton (1981). The correlation matrices were corrected for selection effects and restriction of range by Maier and Grafton using procedures described in Dunbar and Linn (1986).<sup>6</sup> Regressions were estimated using LISREL for six major categories of Military Occupational Specialties (MOS)--Skilled Technical, Skilled Electronic, General Maintenance and Construction, Mechanical Maintenance, Clerical, and Missile Battery

Operators and Food Service Workers--which have close civilian counterparts. The independent variables were the 10 ASVAB 6/7 subtest scores which had counterparts in the ASVAB 8A battery used in the study of the wages and earnings of NLS Youth. The standardized regression coefficients from this analysis are reported in Figures 7-12.

The results for the academic subtests are quite different from the wage rate regressions for young males. Science knowledge which had small negative effects on wage rates, now has positive effects on hands-on measures of job performance in all six MOS clusters, significantly so in 3 MOS clusters and in pooled data. A one standard deviation (SD) increase in science knowledge raises job performance by .057 SD in skilled technical jobs, .072 SD in skilled electronics jobs, .134 SD in general maintenance and construction jobs, .096 SD in mechanical maintenance jobs, .064 SD in clerical jobs, and .076 SD in missile battery operator and food service jobs. The proportionate change in productivity that results is probably between 25 and 40 percent of these numbers.<sup>7</sup> If we assume the SD of true productivity averages 30 percent of the mean wage in these jobs, the average impact of one SD of science competency is about 2.5 percent of the wage.

With the sole exception of the mechanical maintenance MOS cluster, the two mathematical reasoning subtests have much larger effects on SQTs than science knowledge or computational speed. The Math Knowledge subtest assessing algebra and geometry is responsible for most of this effect. A one standard deviation increase in competence in algebra and geometry raises predicted job performance by .121 SD in skilled technical jobs, .261 SD in skilled electronic jobs, .44 SD in general maintenance jobs, .206 SD in clerical jobs and .106 SD for missile battery operators and food service jobs. The arithmetic reasoning test had large positive effects only on performance in clerical (.24 SD) and missile battery and food service (.11 SD) jobs. Assuming that the standard deviation of true productivity is 30 percent of the wage, the impact of a simultaneous one SD increase in both mathematics reasoning subtests is about 7 percent averaging across all six occupations.

The effects of the four "technical" subtests--mechanical comprehension, auto information, shop information and electronics information--are presented at the bottom of figures 7-12. As one might anticipate, these subtests had no effect on job performance in clerical jobs. However, they had very substantial effects on job performance in all the other occupations. A one standard deviation increase in all four of these subtests raises the hands-

Figure 7

Effect of Competencies on  
Job Performance (SQT) of Skilled Technical

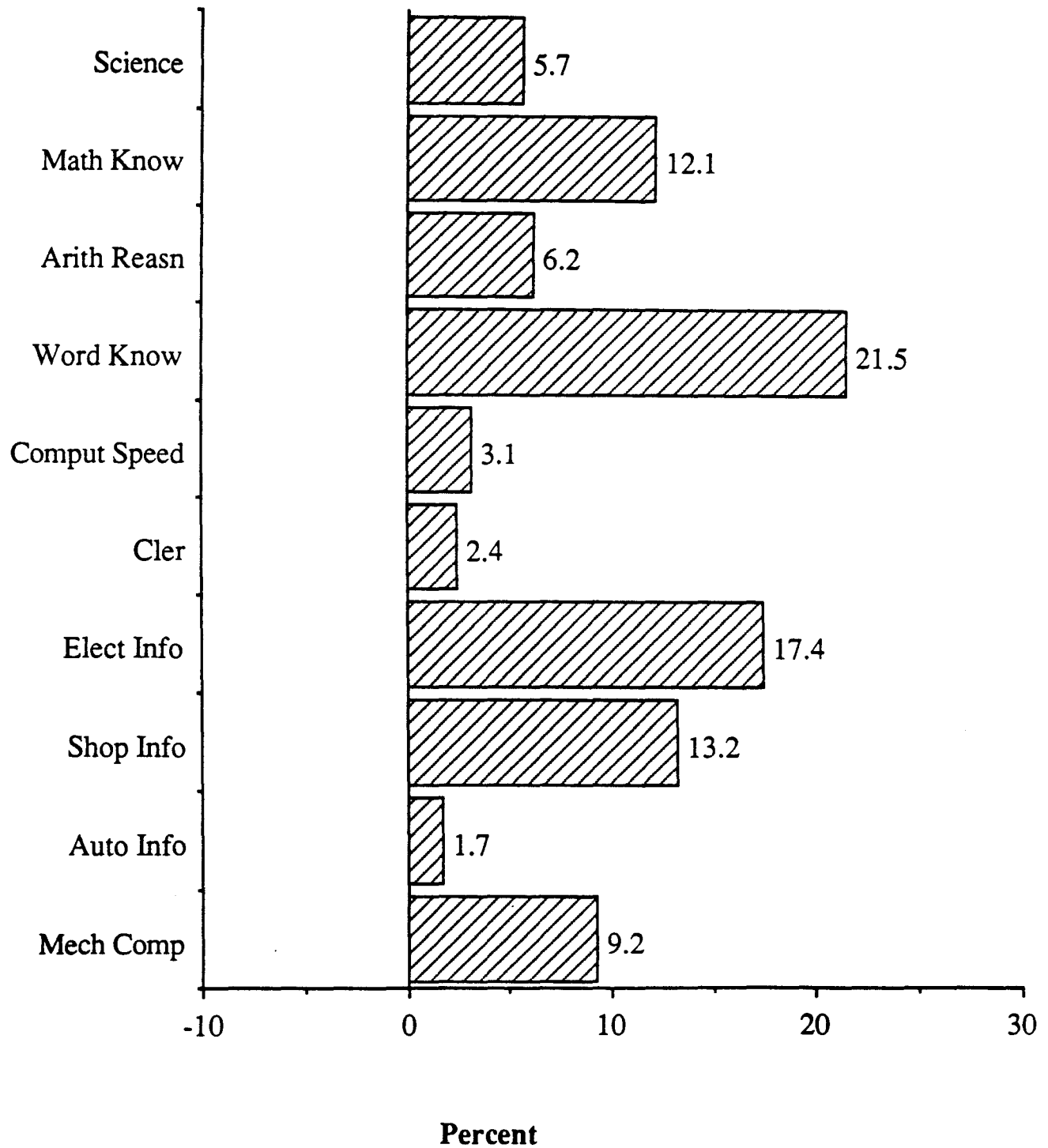


Figure 8

Effect of Competencies on  
Job Performance (SQT) of Skilled Electronic

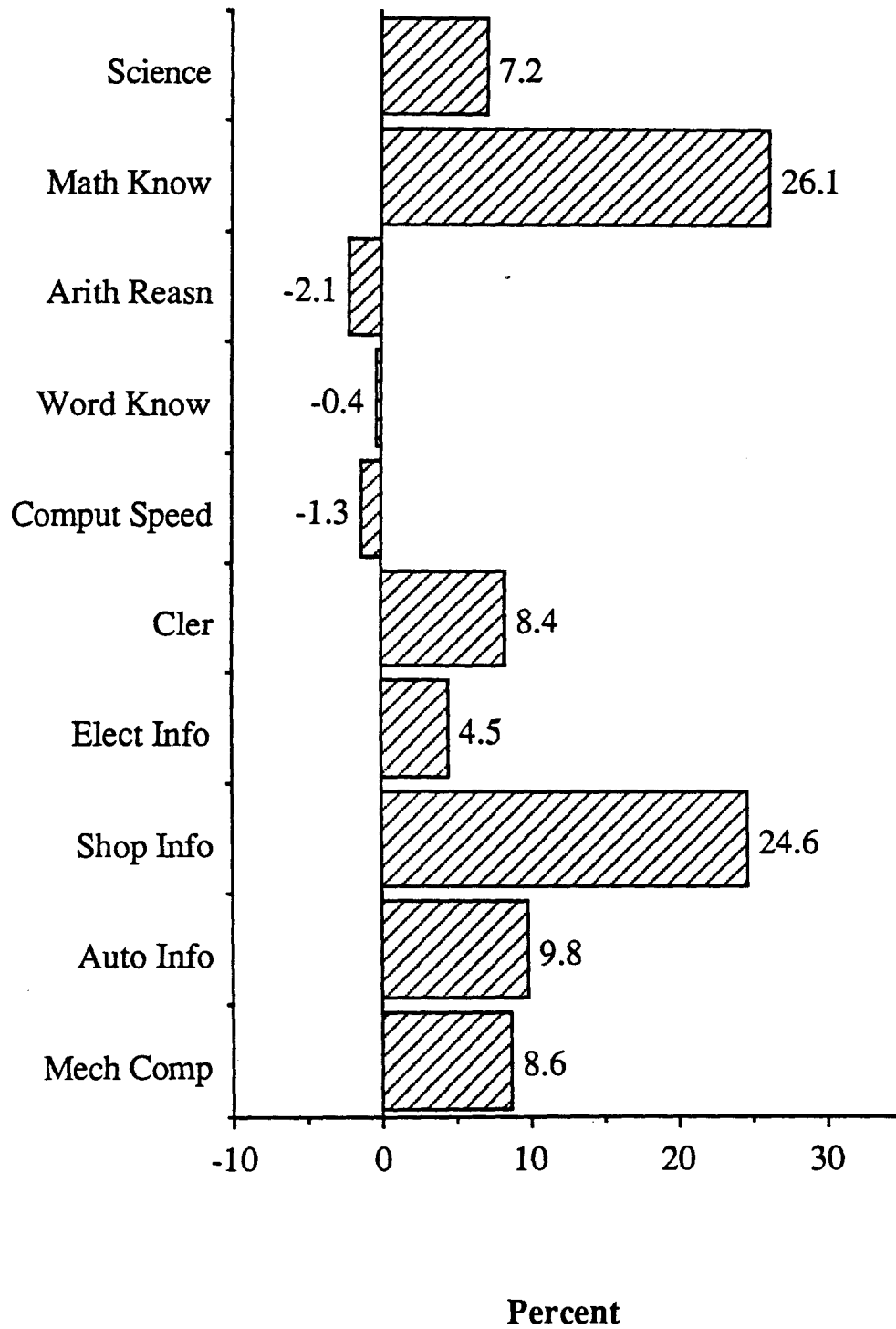


Figure 9

Effect of Competencies on  
Job Performance (SQT) of General Maintenance

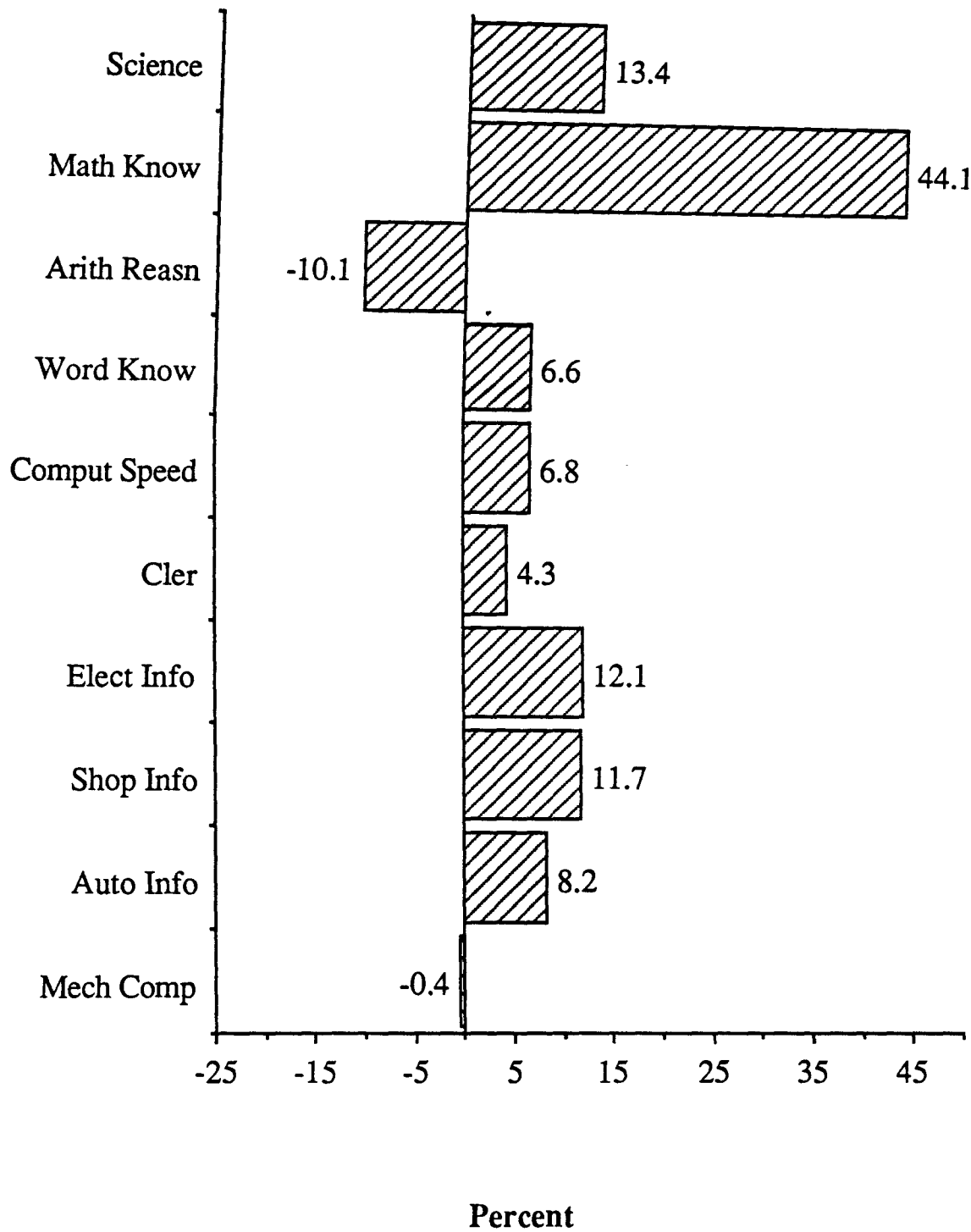


Figure 10

### Effect of Competencies on Job Performance (SQT) of Mechanical Maintenance

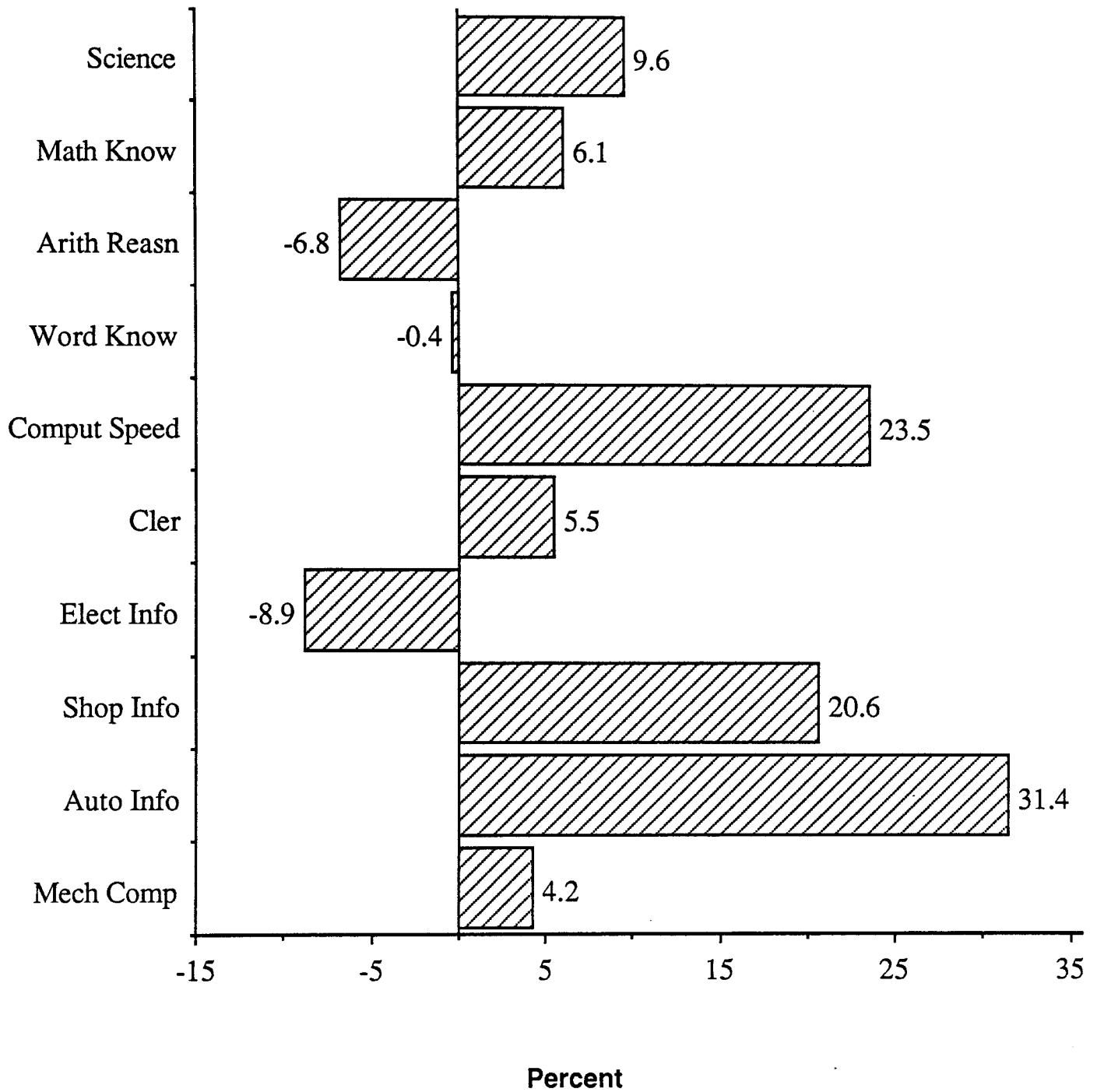


Figure 11

Effect of Competencies on  
Job Performance (SQT) of Missile Battery Operators

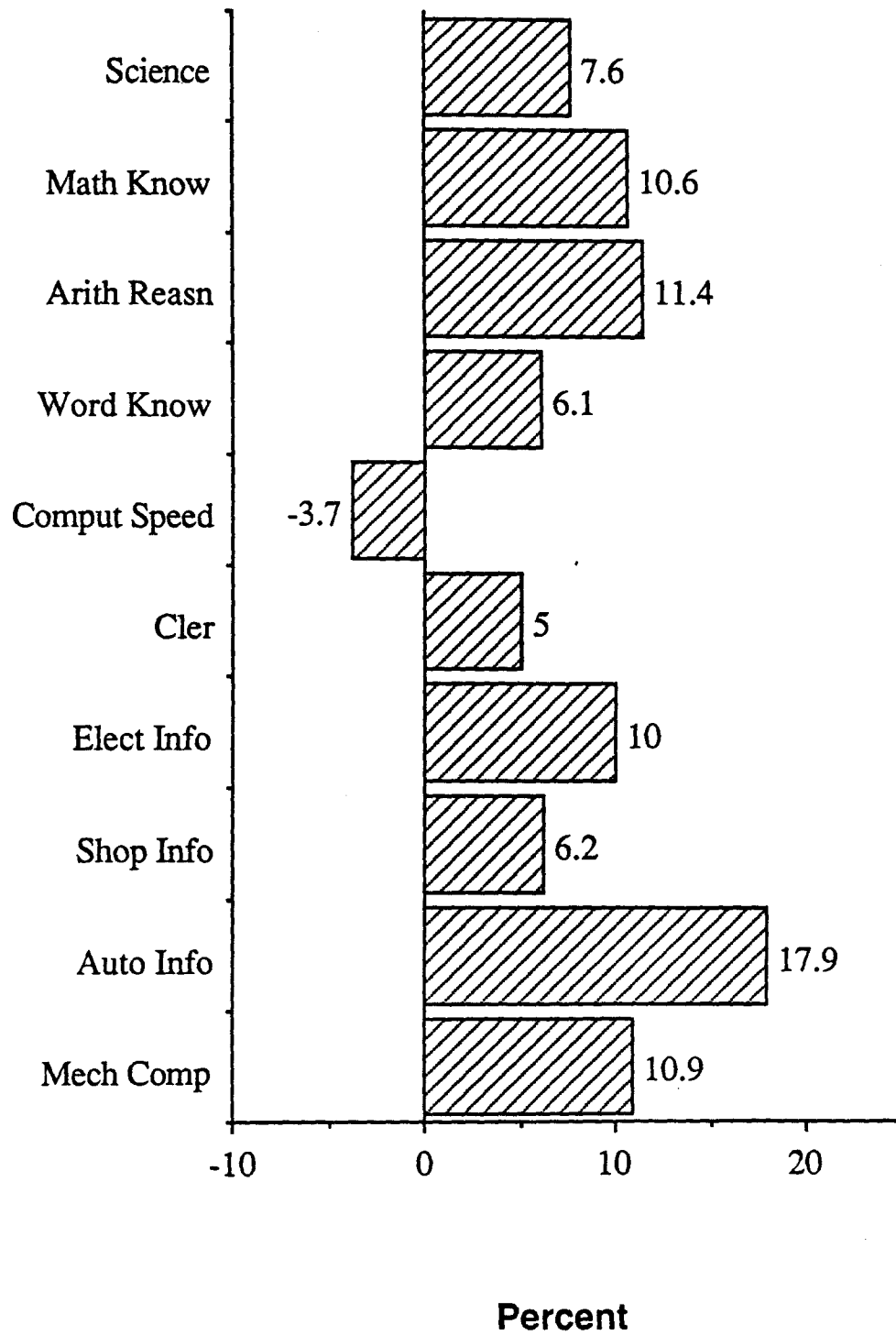
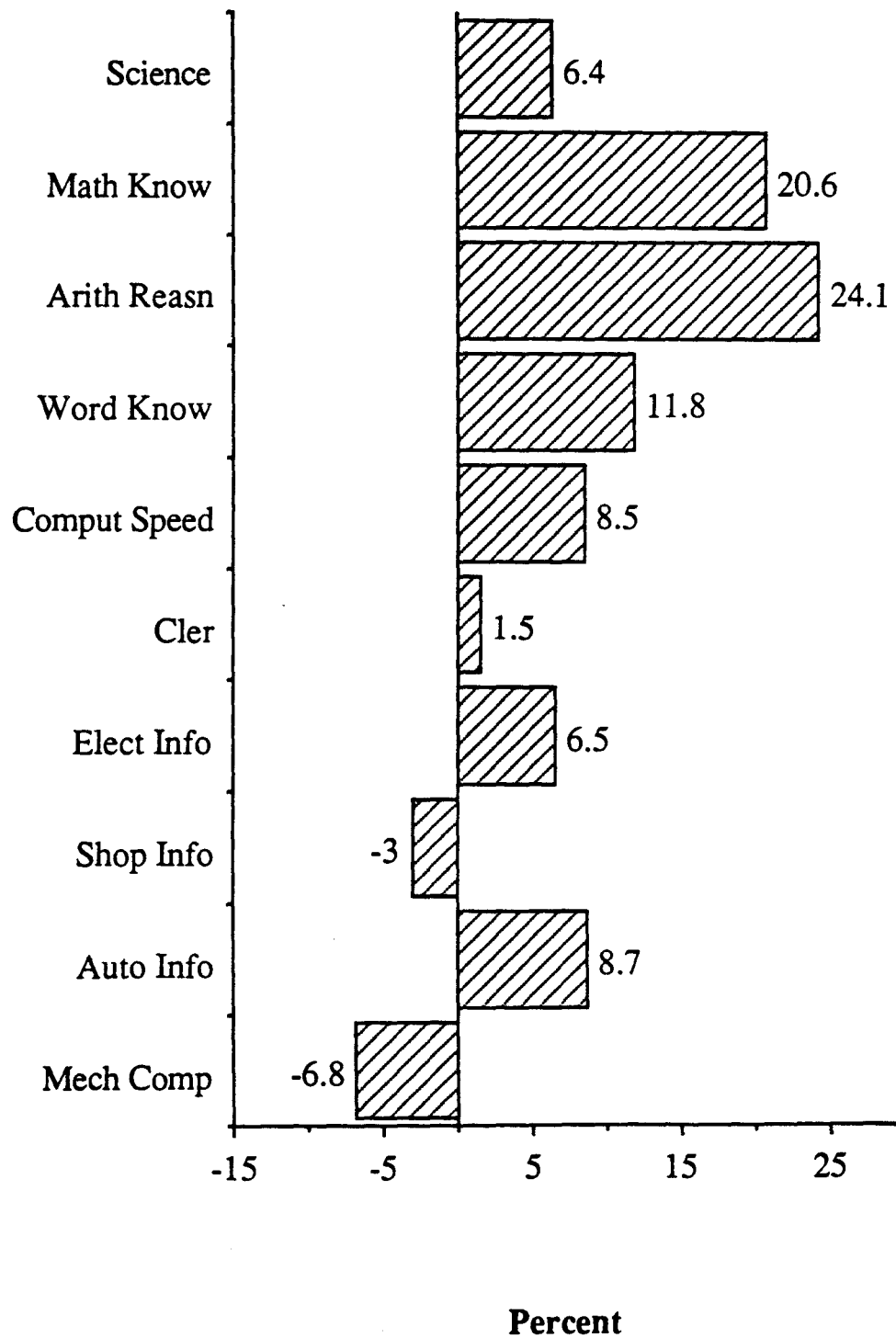




Figure 12

Effect of Competencies on  
Job Performance (SQT) of Clerical



on measure of job performance by .415 SD in skilled technical jobs, by .475 SD in skilled electronics jobs, by .316 SD in general maintenance jobs, by .473 SD in mechanical maintenance jobs and by .450 SD for missile battery operators and food service workers. Averaging over the five non-clerical occupations, a one SD increase in all four of the technical subtests raises productivity by about 13 percent of the wage.

These results provide strong support for the Nation at Risk report's claim that improved mathematics education for the great mass of high school students will improve the productivity of the work force. Doing a better job of teaching the mathematical reasoning skills measured by the ASVAB subtests is clearly going to be worthwhile.

With respect to science, however, the findings are more equivocal. The productivity increase of 2.5 percent per SD appears to be modest. This is probably due to the inadequacies of the ASVAB's 11 minute 24 item General Science subtest. Science competence is very imperfectly measured by this short subtest, and this biases down the estimated effects of science on job performance. Nevertheless, the data clearly do not disprove Shamo's claim that "widespread scientific literacy is not essential to... prepare people for an increasingly technological society". There is a need for new research to determine whether broader and more reliable measures of scientific knowledge and understanding have more substantial effects on job performance in non-technical jobs than the ASVAB's General Science Subtest.

Probably the most striking of the paper's empirical findings is the very large impacts of the ASVAB's technical subtests on both job performance in nonclerical jobs and on the wages and earnings of young males. These results imply that broad **technical literacy** is essential for workers who use and/or maintain equipment that is similar in complexity to that employed in the military.

#### IV. POLICY IMPLICATIONS

The key to motivating students to learn science, mathematics and technology is recognizing and rewarding learning effort and achievement. Some students are attracted to serious study of science, math and technology by an intrinsic fascination with the subject. They must pay, however, a heavy price in the scorn of their peers and lost free time. Society offers them little reward for their effort. Most students are not motivated to study by a love

of the subject. Most "don't like to do any more school work than [they] have to." As a result, far too few high school students put serious time and energy into learning science, math and technology and the society suffers. If this situation is to be turned around, the peer pressure against studying must be eliminated and the rewards for learning must be increased. The full diversity of types and levels of accomplishment need to be signaled so that everyone--no matter how advanced or far behind--faces a reward for greater time and energy devoted to learning. Learning accomplishments need to be described on an absolute scale so that improvements in the quality and rigor of the teaching and greater effort by all students makes everybody better off. Increasing numbers of employers need workers who are competent in science, math and technology. If these employers know who is well educated in these fields, they will provide the rewards needed to motivate study. Ninety-two percent of 10th graders say they "often think about what type of job I will be doing after I finish school"(LSAY, Q. AA13C). If the labor market were to begin rewarding learning in school, high school students would respond by studying harder and local voters would be willing to pay higher taxes so as to have better local schools.

Some might respond to this strategy for achieving excellence by stating a preference for intrinsic over extrinsic motivation of learning. This, however, is a false dichotomy. Nowhere else in our society do we expect people to devote thousands of hours to a difficult task while receiving only intrinsic rewards. Public recognition of achievement and the symbolic and material rewards received by achievers are important generators of intrinsic motivation. They are, in fact, one of the central ways a culture symbolically transmits and promotes its values.

The policy recommendations have been grouped into five categories:

- \* Revision of the science, math and technology curriculum.
- \* School based rewards for learning.
- \* Better signals of accomplishment in science, mathematics and technology,
- \* Reforming college admissions criteria,
- \* School sponsored signals of academic achievement made available to employers.

#### 4.1 Revise Curricula

The analysis of the causes of the American apathy regarding the teaching and learning of science, math and technology has important implications for the curriculum. Many of the weaknesses of math and science curricula--the constant review and repetition of old material, the slow pace and minimal expectations--are adaptations to the low level of effort most students are willing to devote to these subjects. When considering proposed revisions of the curriculum, one must remember that motivating students to take tough courses and to study hard must be a central concern.

A second constraint that must be dealt with is the great diversity of the learning goals and capabilities of high school students. On the NAEP mathematics scale 15 percent of 13 year olds have better mathematics skills than the average 17 year old student and 7 percent of 13 year olds score below the average 9 year old (NAEP 1988b). It is neither feasible nor desirable for all high school students to pursue the same science, mathematics and technology curriculum. Some students will want to pursue natural science in greater depth and rigor than others. Some students will want to concentrate on technology not pure science. Some courses will be easier than others and students will inevitably be able to choose less demanding courses.

State requirements that students take more math and science courses to graduate will have little effect on learning if students meet the requirement by taking undemanding courses. Holding background characteristics and the rigor of the math and science courses constant, an additional three courses in math and science during high school increases the gain in math competency between 10th and 12th grade by only .19 of a grade level equivalent and reduces science gains by .09 of a grade level equivalent and English and social studies gains by .17-.18 of a grade level equivalent. Holding background characteristics and the number of courses constant, taking five college preparatory math and science courses--chemistry, physics, algebra II, trigonometry and calculus--increased the gain on math and science tests by .75 of a grade level equivalent and increased the gain in English and social studies by .34-.44 of a grade level equivalent (see ftn 2 and Bishop 1985). These data clearly imply that learning rates are determined by the rigor not the number of courses taken in a subject.

Another strategy that is bound to fail is setting minimum standards for graduation. Some students arrive in high school so far behind and the consequences of not getting a

diploma are so severe, minimum competency standards are never set very high (and cannot in good conscience be set too high given the constraints on the system). Once they satisfy the minimum, many students stop putting effort into their courses.

How then do we convince students to work hard in science and math courses? How do we induce them to select courses that require a lot of work just to be an average achiever in the class? The answer is **by (1) developing rigorous courses that teach students concepts and material that they will use after leaving high school, (2) convincing students that the science and math being taught is useful by presenting it as solutions to practical real world problems, (3) defining accomplishment in a way that students who work hard will perceive themselves as successful, and then (4) recognizing and rewarding accomplishment.**

Usefulness is an absolutely central criterion for selecting the topics to be included in the science curriculum for three reasons. First, the social benefits of learning derive from the use of the knowledge and skills not from the fact they are in someone's repertoire. Secondly, skills and knowledge that are not used deteriorate very rapidly. In one set of studies, students tested 2 years after taking a course had forgotten 1/2 of the college psychology and zoology, 1/3 of the high school chemistry, and 3/4 of the college botany that had been learned (Pressey and Robinson, 1944). Skills and knowledge that are used are remembered. Consequently, if learning is to produce long term benefits, the competencies developed must continue to be used after the final exam (either in college, the labor market or somewhere else). Finally, usefulness is essential because students are not going to put energy into learning things they perceive to be useless. Furthermore, the labor market is not in the long run going to reward skills and competencies that have no use. Indeed, selecting workers on the basis of a competencies that are not useful in the company's jobs is in most circumstances a violation of Title VII of the Civil Rights Act.

#### Differentiating the Curriculum

By 10th grade most students have a pretty good idea what kinds of jobs they want after finishing their education. Ninety-seven percent can select a particular occupation they expect to be doing at age 40 and 77 percent agree with the statement: "I am quite certain about what kinds of jobs I would enjoy doing when I am older" (LSAY, Q. AA13C & AA22A). Students who are planning scientific careers need to be able to take college preparatory biology, chemistry and physics courses that prepare them for the core courses they

will face in college. The students not planning on scientific careers, however, quite often fail to see how these courses will be useful to them. When asked to rate "How useful do you think the [science course you are now taking] will be to you in your career?" on a five point scale, 23 percent of the high school sophomores selected the "No Use" extreme end of the scale and only 28 percent selected the other "Very Useful" end of the scale (LSAY, Q. AASCI1F).

One approach to this problem, of course, is to point out to students how the material in standard college prep science courses is useful in non-scientific jobs and everyday life. Presumably, science teachers already try to do this. Another approach is to modify the standard curriculum. That is the approach of the new math and science curriculums proposed by the National Council of Teachers of Mathematics (1989) and the American Association for the Advancement of Science (1989). This makes sense in the first 10 years of schooling. There is, however, no standard science curriculum in 11th and 12th grade and it is not realistic to propose that everyone take the same courses. At these grade levels the most effective way to motivate students to take demanding science courses and to study hard is to tailor courses to the student's career interest.

#### Teaching Science and Math by Infusing it into Technology Courses

The analyses of labor market success of young men and of job performance in the military presented in sections 2 and 3 indicates that young people who expect to have jobs in which they use or maintain complicated pieces of equipment should receive a thorough technology education. Computer classes are one example of the kinds of courses needed. High school sophomores described their computer classes as "Very Useful" for their career 53 percent of the time and as of "No Use" only 6 percent of the time (LSAY, Q. AACOMF).

The Principles of Technology (PT) course developed by a consortium of vocational education agencies in 47 states and provinces in association with the Agency for Instructional Technology and the Center for Occupational Research and Development is another example of a course that meets this need very well. This 2 year applied physics course is both academically rigorous and practical. Each six day subunit deals with the unit's major technical principle (eg. resistance) as it applies to one of the four energy systems--mechanical (both rotational and linear), fluidal, electrical and thermal. A subunit usually consists of two days of lectures/discussion, a math skills lab, two days of hands-on physics application labs,

and a subunit review. This approach appears to be quite effective at teaching basic physics. When students enrolled in regular physics and Principles of Technology courses were tested on basic physics concepts at the beginning and end of their junior and senior year in high school, the PT students started out behind the regular physics students but obtained an average score of 81 at the courses completion as compared to an average of 66 for the physics students (Perry, 1989). Another study by John Roper (1989) obtained similar results.

## **4.2 School Based Rewards for Learning**

### **Cooperative Learning**

One effective way of inducing peers to value learning and support effort in school is to reward the group for the individual learning of its members. This is the approach taken in cooperative learning. Research results (Slavin 1985) suggest that the two key ingredients for successful cooperative learning are as follows:

- ° A cooperative incentive structure--awards based on group performance--seems to be essential for students working in groups to get really involved in tutoring and encouraging each other to study.
- ° A system of individual accountability in which everyone's maximum effort must be essential to the group's success and the effort and performance of each group member must be clearly visible to his or her group mates.

For example, students might be grouped into evenly matched teams of 4 or 5 members that are heterogeneous in ability. After the teacher presents new material, the team works together on work sheets to prepare each other for periodic quizzes. The team's score is an average of the scores of team members, and high team scores are recognized on a class bulletin board or through group certificates of achievement.

What seems to happen in cooperative learning is that the team develops an identity of its own, and group norms arise that are different from the norms that hold sway in the student's other classes. The group's identity arises from the extensive personal interaction among group members in the context of working toward a shared goal. Since the group is small and the interaction intense, the effort and success of each team member is known to other teammates. Such knowledge allows the group to reward each team member for his or her contribution to the team goal, and this is what seems to happen.

Laboratory assignments are a natural environment for cooperative learning. There is a tendency, however, for one member of the lab partnership to do all of the planning and interpreting of the experiment. Somehow this must be prevented for the slower student ends up not learning from the exercise. One approach would be to form teams from constituent lab partnerships and to recognize teams on the basis of quizzes given at the end of the lab or the following day.

### Honoring Academic Achievement

Schools should strengthen their awards and honors system for accomplishments in science, mathematics and technology. The medals, trophies, and school letters awarded in interscholastic athletics are a powerful motivator of achievement on the playing field. Academic pursuits need a similar system of reinforcement. Awards and honors systems should be designed so that almost every student can receive at least one award or honor before graduation if he or she makes the effort. Outstanding academic performance (e.g., high grades or high test scores) should not be the only way of defining excellence. Awards could be given for progress made in science and math, for participation in science and math contests, for perfect attendance records in science and math classes and for student of the week (criteria could vary weekly). The standard for making an award should be criterion referenced: if greater numbers achieve the standard of excellence, more awards should be given. Periodically, the parents of the most recent award winners and sponsoring teachers should be invited to an evening assembly at which time the principal would award the students the certificate or plaque recognizing their accomplishments.

A prominent place in the school should be reserved for bulletin boards where pictures of the most recent winners and reasons for their receiving recognition could be posted. Another form of recognition could be displays of student work: science projects, applied technology projects, and so forth.

### A National Network of Science, Math and Technology Clubs

At present only 3.2 percent of high school sophomores are members of a science club, only 2.5 percent are members of a math club and only 1.6 percent are members of a computer club (LSAY, Q. BA10K-BA10M). Memberships in these clubs should be increased and the clubs should be stitched together into a national network. The national student



organizations would sponsor interschool competitions, visits to science museums and science and technology project competitions that would feed into national competitions like the Westinghouse Science projects awards. The national organizations would function in much the same way as the national offices of Boy Scouts, Future Farmers of America and VICA. They would provide training to teachers and student leaders and develop program activity packets to help local science and math teachers devise activities for their club.

### **4.3 Better Signals of Accomplishment in Science, Math and Technology**

#### **Develop Better Assessment Mechanisms**

As student recognition and rewards come increasingly to depend on the results of school assessments of competency, it becomes more and more important that we improve our methods of assessing math, science and technological achievement. Linking assessment to curriculum also implies a need for a greater diversity of assessment mechanisms. States should not be prevented from having their own unique curriculum simply because examinations keyed to this curriculum are not available. However, the need for multiple versions and for fairness to minorities make test development very expensive. The federal government should underwrite state consortia and other organizations that seek to develop alternatives to currently available tests and assessment mechanisms. Priority needs to go to developing methods of assessing higher order thinking skills and hands on performance through simulations, judged portfolios and demonstrations of skills conducted in front of judges. High cost has been the primary barrier to the use of these richer forms of assessment. Consequently, consideration should be given to subsidizing these more costly assessment mechanisms.

#### **Instituting Statewide Achievement Examinations**

States should adopt statewide tests/assessments of competency and knowledge that are specific to the curriculum being taught (e.g. New York State's Regents Examinations) and then give students a competency profile/portfolio certifying performance on these exams which could be used as an aid in searching for jobs. Admission to state universities and merit based scholarships should be based on these achievement exams and on AP exams. In addition to their incentive effects, these examinations/assessments would:

- Better inform students and parents about how well the student is doing and thus help parents work with teachers to improve their children's performance.
- Make the relationship between teachers and students more cooperative, with the teacher and students working jointly to prepare the students for the exam.
- Create a database that school boards and parents could use to evaluate the quality of education being provided by their local school.
- Enable employers to use scores on these examinations to help improve their selection of new employees. If the uncertainties involved in hiring are reduced, expanding employment will become more profitable, total employment will increase, and recent high school graduates will be better able to compete with more experienced workers for top quality jobs.

#### **4.4 Reform College Admission Policies**

##### **Expand Advanced Placement Courses**

The Advanced Placement program is a cooperative educational endeavor which offers course descriptions, examinations and sets of curricular materials in 28 different academic subjects. Students who take these courses and pass the examinations receive college credit for high school work.

The students of Jaimie Escalante's Advanced Placement calculus classes have demonstrated how young people from disadvantaged backgrounds can use the AP program as an upward mobility escalator. The James A. Garfield High School student body is predominantly disadvantaged minorities; yet it accounts for 17 percent of all Mexican Americans taking the AP calculus exam and 32 percent of all Mexican Americans who pass the more difficult BC form of the test (Berlin and Sum 1988). There is no secret about how they did it; they worked extremely hard. Students signed a contract committing themselves to extra homework and extra time at school and they lived up to the commitment. What this experience establishes is that minority youngsters from disadvantaged backgrounds can be persuaded to study just as hard as academic track students in Japan, Finland and England and

that if they do, they will achieve at the same level. Escalante cast aside the zero sum competition of grades and rank in class and set for his students a very difficult externally defined goal. He persuaded them that they could succeed and that there was great honor in taking on the challenge. The success at Garfield High is replicable.

Expanding the AP program should be a center piece of any effort to promote excellence in science, mathematics and technology education. It clearly meets a felt need for it is growing rapidly. The numbers of students taking AP exams more than doubled between 1983 and 1988. Nevertheless, only 8022 of the 22,902 US high schools participate in the Advanced Placement Program and only 52 AP exams are taken on average in each participating high school. In the Class of 1988 only 2.5 percent took the AP calculus exam, .7 percent took the AP computer science exam, 1.1 percent took AP biology, .7 percent took AP chemistry and .6 percent took AP physics. (The College Board 1988). The nation should set a goal of doubling these percentages every two years for the next decade. New AP exams should be established in principles of technology, electronics, algebra, geometry and trigonometry, probability and statistics, psychology and business mathematics so that larger numbers of 10th and 11th graders and students planning to attend 2 year technical colleges may participate in the AP program. Acting in concert, the college presidents of a large group of selective 2 year and 4 year colleges should send a letter to every high school principal in the country (with copy to the school board and local newspaper) urging them to establish AP courses in science, mathematics and technology. They should also announce that starting in 1993, students seeking admission to their school should have taken and passed at least one AP course in junior year and be taking more than one AP course their senior year.<sup>8</sup>

The federal government can facilitate the growth of the AP program by underwriting the development of AP exams for new subjects, by financing summer institutes for the teachers of AP courses and by offering a \$100. AP Excellence Award (larger if the student is eligible for Pell Grant aid) to every student who gets a 3 or above on an AP exam and a \$150. award for getting a top score. To insure that attending a summer institute is considered a plum, compensation should be generous. In 1988 approximately 42,000 teachers taught AP courses. Rapid expansion of the program will require a yearly increase of 20,000 in the stock of teachers teaching AP courses and if 30 percent of the increment to the stock were to experience summer institute training for 6 weeks, the cost would be about 42 million dollars.

In 1988 286,009 students would have been eligible for an AP excellence award so the program would have cost under 40 million dollars. If a good deal of publicity were attached to these awards, they would induce a major expansion of the program.

Induce Colleges to Drop the SAT and ACT Tests from their selection criteria and substitute scores on AP and state sponsored achievement exams/assessments which cover the curriculum taught in High School

While national tests are necessary, the Scholastic Aptitude Test (SAT) is not the kind of test that is helpful. The SAT suffers from two very serious limitations: the limited range of the achievements that are evaluated and its multiple choice format. The test was designed to be curriculum free. To the extent that it evaluates the students' understanding of material taught in schools, the material it covers is vocabulary and elementary and junior high mathematics. Most of the college preparatory subjects studied in high school--science, social science, history, geography, literature, technology, art, music, computers, calculus, probability and statistics--are completely absent from the test. As a result, it fails to generate incentives to take the more demanding courses or to study hard. The test advertises itself as an ability test but is in fact an achievement test measuring a very limited range of achievements (Jencks and Crouse 1982). Jencks and Crouse have recommended that either the SAT evaluate a much broader range of achievements or be dropped in favor of an expanded set of AP examinations. Knowledge and understanding of literature, history, technology, science and higher level mathematics should all be assessed. These exams should not be limited to a multiple choice format and essays and extended answers should be required where appropriate.

#### **4.5 Induce Employers to Reward Science and Math Learning**

At present recent high school graduates are not considered for jobs with good wages and promotion opportunities because job applicants who lack a lengthy track record are not considered for such jobs. Extensive work experience is considered essential partly because it contributes to productivity but also because it produces signals of competence and reliability that employers use to identify who is most qualified. Recent high school graduates have no such record and information on the student's high school performance is generally not available, so the entire graduating class appears to American employers as one undifferentiated mass of unskilled and undisciplined workers. New York Life Insurance had such a difficult