Chapter 4

Thinking About Learning Science

Photo credit: William Mills, Montgomery County Public Schools

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Thinking About Learning Science

We should spend less time ranking children and more time helping them identify their natural competencies and gifts and cultivate them. There are hundreds of ways to succeed, and many, many different abilities that will help you get there.

Howard Gardner, ***1983***

After chapters on students, schools, and teachers, it might seem odd to ask in a separate chapter: How do students learn science and mathematics? No answer will be found in the following pages. Indeed, this question now occupies several cadres of scholars and educators—neuroscientists, learning theorists, school psychologists, and an abundance of classroom teachers. Educational policy analysts have the luxury of politely raising the question, acknowledging its complexity, and substituting a slightly more tractable set of questions: How can more students be successful in science and mathematics? Does science and mathematics education search for and select a particular type of student? Is a certain learning style favored in the teaching and learning of these subjects? If so, is a self-fulfilling prophecy at work? If a certain kind of learning style is appropriate to science or mathematics, can it be promoted through programs for "gifted" or "talented" students? What can be done to correct misconceptions (held both by students and teachers), to spur creativity, to develop "higher order thinking skills," and to place more students on pathways to learning science and mathematics?[1] This chapter presents a select menu of needs, taking few orders for satisfying them.[2]

[1] Two foci of Federal support (by the National Science Foundation and the Department of Education) have been new environments for teaching mathematics and science students, and educational research on teaching and learning. Both are built on the premise that students' own experiences and intuitive explanations of scientific phenomena fuel learning. For example, see Educational Technology Center, *Making Sense of the Future* (Cambridge, MA: Harvard Graduate School of Education, January 1988); Audrey Champagne and Leslie Hornig, ***Students and Science Learning*** (Washington, DC: American Association for the Advancement of Science, 1987), chs. 1-2; Jan Hawkins and Roy D. Pea, "Tools for Bridging the Cultures of Everyday and Scientific Thinking," *Journal of Research in Science Teaching, vol. 24, No. 4, 1987,* pp. 291-307; Rosalind Driver, ***The Pupil as Scientist?*** (Philadelphia, PA: Open University Press, 1983); ERIC Clearinghouse for Science, Mathematics, and Environmental Education, ***Science Misconceptions Research and Some Implications for the Teaching of Science to Elementary School Students,*** Science Education Digest No. 1 (Columbus, OH: 1987); ERIC Clearinghouse for Science, Mathematics, and Environmental Education, ***Secondary School Students' Comprehension of Science Concepts: Some Findings From Misconceptions Research,*** Science Education Digest No. 2 (Columbus, OH: 1987); and Cornell University, Department of Education, "Proceedings of the Second International Seminar on Misconceptions and Educational Strategies in Science and Mathematics," 1987.

[2] The revision of this chapter has benefited especially from the commentary of Audrey Champagne, American Association for the Advancement of Science, personal communication, August 1988.

STUDENTS AND SCIENCE LEARNING

Students need to discover and recognize how they best learn; this aids in relating their intuitive knowledge to the knowledge conveyed in the classroom. Techniques have been devised to help children bridge their prior conceptions to the results of scientific inquiry.[3] If students' development of reasoning and analytic skills is closely

[3] For some of this pioneering work, see Joseph D. Novak and D. Bob Gowin, ***Learning How To Learn (New*** York, NY: Cambridge University Press, 1985).

linked to their assimilation of knowledge about particular subjects, it makes little sense to divorce the two in teaching science. Methods of inquiry and analysis, acquired via laboratory and hands-on experiences, have to be taught together with facts about particular problems or fields. All this takes time, and it maybe that the amount of material covered in the typical science curriculum should be reduced, reserving instruction time for the use of hands-on techniques.[4]

The need to increase emphasis on problem solving and thinking skills is often referred to as improving students' higher order thinking skills or "creative thinking. " Higher order thinking is the ability to infer and reason in an abstract way, rather than merely memorizing and recalling single items of information. These skills have always been important, but many analysts believe that they will be part of the "new basics" for tomorrow's high-technology work forces

[4]In addition, computers and other interactive technologies appear to be very promising in facilitating students' construction of scientific and mathematical phenomena, and some teaching packages have been designed for this purpose. In designing effective science and mathematics education programs, experts in particular scientific fields need to pool resources with cognitive scientists and practicing teachers. See Barbara Vobejda, "A Mathematician's Research on Math Instruction, " *Educational Researcher, vol. 16, No. 9,* December *1987,* pp. 9-12.

'There is, however, no generally agreed on framework that defines the distinction between a higher order skill, a lower order skill, or any other kind of thinking skill. See Audrey B. Champagne, "Definition and Assessment of the Higher Order Cognitive Skills, " *NARST Research Matters . . . To the Science Teacher* (Cincinnati, OH: University of Cincinnati, 1987); Lauren B. Resnick, *Education and Learning to Think* (Washington, DC: National Academy Press, 1987); Lynn Steen, "The Science of Patterns," *Science, vol. 240,* Apr. 29, 1988, pp. 611-616; Richard J. Murnane, Harvard University, Graduate School of Education, "U.S. Education and the Productivity of the Work Force: Looking Ahead, " unpublished paper, June 1988; and *Educational Leadership,* "Teaching Thinking Throughout the Curriculum, " vol. **45,** April 1988, pp. *3-31.*

Pboto credit William Mills. Montgomery County Public Schools

Science awards, contests, and fairs bestow public recognition on science achievers and provide hands-on experiences for many students.

The concept of higher order thinking may be a metaphor for drastic reform of schools; valid or not, many States are investing money in it.[6] A particular focus of this trend is testing, which is widely believed to be one of the main forces that perpetuates lower order thinking skills in the present day curriculum. In a sense, two related trends—a transition in the generally accepted theory of student learning and the pressure for a higher level curriculum—could lead to positive improvements in student learning of mathematics and science. But change will be slow in coming.[7]

Learning Styles

There are more similarities in how people learn than there are differences. However, there is mounting evidence that different modes (such as oral, written, and diagrammatic presentation of material) are effective with different students. These differences are believed to exist both among individuals and groups.[8]

Individual differences have been clear to teachers for years. Some students concentrate on rote memorization of facts, some explore with their hands, others are much more visual and respond best to graphical and pictorial presentation of material, while others learn via more abstract imagery. Research is beginning to clarify these differences and to explore their implications for teaching and learning.

Various models of learning styles have been devised. Each is designed to help teaching become more closely attuned to the ways different students learn, although so far these models have had limited effect in classroom practice and none is generally accepted.[9] This research builds on a long tradition of studies by philosophers, psychologists, and cognitive scientists that traces differences in learning to cultural and family backgrounds. Some differences, however, are physiological in nature, such as whether students work best at night or in the morning, and their susceptibility to extremes of light, sound, and heat. How these differences apply to the learning of science and mathematics is just beginning to be clarified. But the heavy focus of elementary and secondary mathematics and science courses on the learning and regurgitation of discrete, abstract facts has already alerted the science education community to the need for more hands-on programs, in order to break down this misleading image of what science is like.[10]

Since science and engineering have been historically populated by white males, it has been assumed that teaching approaches that are successful with this population are appropriate for all students. It is further alleged that departures from these approaches are not rewarded, and thus perpetuate the factors that deter women and most racial and ethnic minorities from considering science and engineering careers. Such deterrents are reflected in the prejudice and discrimination operating in these fields. (See box 4-A.)

As a result of this concept of how science should be taught and learned, science education in the United States, some assert, is obsessed with the testing knowledge of facts to the exclusion of four,

[6]See, for example, Rita Dunn and Shirley A. Griggs, ***Learning Styles: Quiet Revolution in American Secondary Schools*** (Reston, VA: National Association of Secondary School Principals, **1988).**

[7]A recent initiative, called Project XL, by the U.S. Patent and Trademark Office, together with the Departments of Commerce, Energy, and Education, aims to develop inventive thinking and problem-solving skills in students. See Virginia Sowers, "Patent Office Spearheads Creative-Thinking Project," ***Engineering Times, vol.*** 10, No. ***4,*** April 1988, p. 9.

[8]For example, some suggest that whites and Blacks, as well as males and females, often have characteristically different learning styles. Not surprisingly, the hypothesis that learning styles differ by race, ethnicity, and gender is highly controversial (discussed below).

[9]Christine I. Bennett ***Comprehensive Multicultural Education: Theory and Practice*** (Newton, MA: Allyn & Bacon, 1986), chs. 4-5. A series of eight filmstrips produced by Madison Workshops (Dept. E-W/1379 Grace Street, Madison Schools, Mansfield, OH, **44905)** are now **available under** the title "Learning Styles—An Alternative for Achievement. " The films cover the following themes: research and learning style instruments, classification of instructional materials to accommodate student learning styles, brain dominance and learning styles, an explanation for parents, the gifted student, an approach to homework, and students with specific needs. Engineering educators are also beginning to address the importance of matching teaching and learning styles in their students. Richard M. Felder and Linda K. Silverman, "Learning and Teaching Styles in Engineering Education, " ***Engineering Education,*** vol. **78,** ***No. 7,*** April 1988, pp. 674-681.

[10]For example, see Mary Budd Rowe, "Minimizing Student Loss in Freshman and Sophomore Science Courses, " ***Research in College Science Teaching, vol.*** **5,** ***No. 5,*** May 1976, pp. 333-334; and Paul J. Kuerbis, "Learning Styles and Science Teaching, " ***NARST Research Matters . . To the Science Teacher*** (Cincinnati, OH: University of Cincinnati, n.d.).

Box 4-A.-A Black Learning Style?

The relation between scientific values and learning styles is reflected in the concern to improve high school completion rates among "at-risk" students. A recent booklet, written by the New York State Education Department to help teachers of at-risk students improve completion rates, included discussion of minority learning styles. A storm of protest among both minority and majority politicians and educators ensued.[1] The booklet states:

> . . . understanding various learning styles is . . . important, Several researchers have noted that the traditional classroom is built, for the most part, around the Anglo-American cultural learning styles which emphasizes the manipulations of objects such as books, listening stations, learning centers, programmed instruction and so forth. Children's racial, ethnic and emotional backgrounds and cultures influence the manner in which they learn concepts and process information. For example, qualities noted in African-Americans include:
>
> - the tendency to view things in their entirety and not in isolated parts;
> - a preference for inferential reasoning rather than deductive or inductive reasoning;
> - the tendency to approximate space, number and time instead of aiming for complete accuracy;
> - an emphasis on novelty, personal freedom, and distinctiveness; and
> - a resistance to becoming "word" dependent, but developing a proficiency in nonverbal as well as verbal communication.[2]

The existence of a Black learning style partly reflects the acceptance of Black culture in American society. At issue is whether differences arise primarily for socioeconomic or for cultural reasons, and which source is dominant. Some argue that the cultural attributes derived from membership of a particular social class are more important than cultural differences based on race. Others suggest that Blacks have created a unique Black-American culture, rooted in African traditions but adapted by the American experience, that outweighs socioeconomic factors.[3]

Several educators have argued that the cultural style and world view of Blacks had been "bastardized" by the dominant culture (the "Anglo-European cosmology") and by its educational system. White children are never asked to span and understand both Black and white cultures, let alone the subcultures within each of them, in the way that Black children are. Specifically, some claim that Black English should be accepted as a distinctive variant of standard English. The difference arises from the strong oral, rather than written, tradition of Black culture. Blacks use a more descriptive, metaphorical, context-dependent language, with few synonyms, compared with standard English. They favor the second-person ("you") rather than the third-person ("he/she"). The result is a language that is more conversational, poetic, and symbolic than that used by whites; the style in which things are said, for example in-public speeches, can be as important as its content. Some argue that the idioms and concepts of Black English actually inhibit traditional mathematics and science learning. However, these same observers believe teaching can be modified and that, ultimately, Black English is as capable of expressing mathematical concepts as is standard English, although it may use different forms.'

A related difference occurs between the intellectual heritages and styles of inquiry of Blacks and white-Europeans. Some Blacks argue that African-American culture is more affective and "cognitively-united" in a faith-reason-emotion interdependence than is the prevailing white-European culture. Researchers on Black cognitive style speak of a "feeling intelligence" and the "aesthetic mind." They are suggesting that this style is built on what people feel and experience, and analyzes the world against that background, rather than through the European traditions of a world of universal facts and knowledge and a divorce between analysis within the mind and the feelings of the body.[5]

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[1] Mark A. Uhlig, "Learning Style of Minorities To Be Studied," *New York Times*, Nov. 21, 1987, p. A29; William Raspberry, "Different Learning 'Styles'," *Washington Post*, Nov. 18, 1987; and Janice E. Hale, *Black Children, Their Roots, Culture, and Learning Styles* (Provo, UT: Brigham Young University Press, 1982), esp. chs. 1-2, 7.

[2] The New York State Education Department, "Increasing High School Completion Rates: A Framework for State and Local Action," a working paper of the Board of Regents, July 1987, pp. 15-16.

[3] See Kofi Lomotey, "Black Principals for Black Students: Some Preliminary Observations," *Urban Education*, vol. 22, No. 2, July 1987, pp. 173-181.

[4] Eleanor Wilson Orr, *Twice as Less: Black English and the Performance of Black Students in Mathematics and Science* (New York, NY: W.W. Norton & Co., 1987).

[5] Because commonly used teaching techniques are rooted in the European tradition, they can be ruthless with Blacks' different cultural and intellectual heritage. The educational system beats the "affective" out of students; its highest value is the neutral lecture-style teaching format, in which the lecturer shuns emotional involvement, eye contact, or voice modulation, and the students are passive absorbers of facts. See James A. Anderson, "Western Educational Systems in Conflict With Learning Styles of Minority Students," presented at the Second National Conference on Black Student Retention in Higher Education, Atlanta, GA, Nov. 4, 1986.

Not all Black educators agree on the importance, or even the existence, of a Black learning style in science and mathematics. They point out that there is a single accepted language of scientific and mathematical concepts that students who wish to progress in these fields must understand. Thus, although there might be different teaching approaches, they must all converge on the universally accepted language and content of mathematics and science.

Learning style differences may also apply to Native Americans and other racial and ethnic groups. One study of the Navajo culture suggests that, in that culture, students learn skills by watching a competent adult performing the action and then gradually taking over more of the action. Finally, the student goes off to perform the skill in private, to verify that he or she has mastered the skill. All this is accomplished with a minimum of oral communication. In schools, however, students are expected to acquire and demonstrate skills almost simultaneously, to test them in public (in front of the teacher and other students), and to learn and test skills orally. It is argued that this clash of styles of learning can seriously inhibit learning by Navajo students.[6]

Science and mathematics education that recognizes diversity will contribute more to the health of science and engineering than one of narrow gauge that alienates bright, creative, risk-taking students. Science would both benefit and change from this recognition, as the skills that the existing system culls out would refine definitions of scientific "productivity" and "creativity."

[6]Christine I. Bennett, *Comprehensive Multicultural Education: Theory and Practice* (Newton, MA: A1lyn & Bacon, 1986), pp. 96-97.

and possibly other, domains: processes, creativity, attitudes, and applications.[11] In their most colorful summaries, some observers have argued that the United States, by accident rather than by design, practices "Westist, sexist, and testist" science education.[12] This approach, if accurate, is more harmful than simply deterring women and minorities from entering science, for it also discourages those whose talents lie in the other four domains and who might also contribute to science.[13]

[11]Robert E. Yager, "Assess All Five Domains of Science," *The Science Teacher*, vol. 54, No. 7, October 1987, pp. 33-37.

[12]See Howard Gardner, "Beyond the IQ: Education and Human Development," *National Forum*, vol. *68, No. 2,* spring *1988,* pp. 4-7, and accompanying articles in this special issue, under the title "Beyond Intelligence Testing."

[13]Evelyn Fox Keller, a scholar of women in science, has vigorously championed this point of view. She states that:

> The exclusion of values culturally relegated to the female domain has led to an effective 'masculinization' of science—to an unwitting alliance between scientific values and the ideals of masculinity embraced by our particular culture. The question that directly follows from this recognition is. To what extent has such an alliance subverted our best hopes for science, our very aspirations to objectivity and universality?

See Evelyn Fox Keller, "Women Scientists and Feminist Critics of Science," *Daedalus*, vol. 116, No. 4, fall **1987,** p. **80;** and Evelyn Fox Keller, "Feminism and Science," Sex *and Scientific Inquiry,* Sandra Harding and Jean F. O'Barr (eds.) (Chicago, IL: University of Chicago Press, 1987), pp. 233-246.

SCIENCE-INTENSIVE ENVIRONMENTS

One institutional response to individual and group differences in learning has been the creation of educational environments that give students greater exposure to mathematics and science than they get in regular schools and classes. Some schools specialize in these subjects. Many schools also provide special classes, including those in mathematics and science, for the so-called gifted and talented, Many students also participate in science outside the classroom, for example, in research participation programs in science laboratories. (See ch. 5.) Special schools and classes are clearly designed to have special effects on children, such as nurturing or maintaining their interest, or expediting and enriching their progress through the regular mathematics and science curriculum. This section reviews data on the extent of these special environments and the effects they have.

An Overview of State Programs and Schools

A few States have established special regional or statewide schools for mathematics and science, often in conjunction with private funding from industry. Illinois, Louisiana, Michigan, North Carolina, Pennsylvania, Texas, and Virginia directly fund statewide schools that provide specialized subject area study. (See table 4-l.) **A** total of 15 States sponsor, in whole or in part, schools that focus on science and mathematics; and two more are reportedly making plans to follow suit.

In addition or as an alternative to special schools, a number of States sponsor summer enrichment programs in mathematics and science. These activities are less costly than special schools and consequently more popular with the States. Twenty States offer summer programs in science and mathematics, although some of them have only very small enrollments. Florida appropriated over $1.2 million last year for such programs.

More than **30** States also have programs designed to improve the participation of women and minorities in science and mathematics. Several Northwestern States have programs designed for Native Americans.[14] Various States have begun sponsoring special recognition programs for students in mathematics and science, such as State fairs and knowledge bowls. California's Golden State Examination, established under the Hughes-Hart Educational Reform movement in 1983, is designed to identify and recognize honors-level achievement by students in specific subject areas, which include mathematics and science, and is the most comprehensive State-sponsored program nationally.

Many recognition and award programs are privately supported by professional organizations or business and industry, or jointly supported by several sources (including State and Federal Government). These types of programs often begin at the local or regional level and end at the national level; Invention Convention and Math-Counts are examples. The Westinghouse Science Talent Search and the West Virginia National Youth Science Camp are privately funded national recognition programs.

[14] Council of Chief State School Officers, Equity ***and Excellence: A Dual Thrust in Mathematics and Science Education*** (Washington, DC: November 1987).

Table 4-1 —State-Funded Schools That Specialize in Science, Mathematics, and Engineering

Illinois
- Illinois Mathematics and Science Academy, Aurora

Louisiana
- Louisiana School for Science, Mathematics, and the Arts, Northwestern State University, Natchitoches

Michigan
- Kalamazoo Area Mathematics and Science Academy

North Carolina
- North Carolina School of Science and Mathematics, Durham

Pennsylvania
- Pennsylvania Governor's School for the Sciences, at Carnegie-Mellon University
- Pennsylvania Governor's School for Agriculture, Pennsylvania State University

Texas
- Science Academy of Austin

Virginia
- New Horizon Magnet School for Science
- Roanoke Governor's School for Science and Mathematics, Roanoke
- Thomas Jefferson High School for Science and Technology, Alexandria
- Central Virginia Governor's School for Science and Technology

SOURCE: Office of Technology Assessment, 1988; based on Education Commission of the States, *Survey of State Initiatives to Improve Science and Mathematics Education* (Denver, CO: September 1987); and data from the National Consortium of Specialized Schools in Mathematics, Science, and Technology.

Science= intensive Schools

Science-intensive schools provide special environments for the study and practice of science and mathematics. Such schools are thought to attract students interested in science and engineering (instead of converting students to such careers), but national data are lacking to support or refute this contention. Such schools tend to attract teachers as well, and are reputed to provide high-quality instruction in mathematics and science. They are generally popular with parents, if for no other reason than they expand the choices beyond the neighborhood public school.

There are three types of science-intensive schools: well-established city-sponsored mathematics and science schools; State-sponsored schools; and magnet schools in urban areas, created to promote racial desegregation, which have mathematics or science as their theme. (See box 4-B.)

Box 4-B.—Science-Intensive Environments: Two Examples

I. The Governor's School of Science and Mathematics, Durham, North Carolina

This school became the first publicly financed residential high school in the United States devoted to science and mathematics when it opened in 1980. Funded directly by the State legislature, together with private donations, it has become a unique and exciting model for precollege science and engineering education. A recent survey found that about 80 percent of its graduates went on to science and engineering majors in college and two-thirds went to college within the State.*

The school is located in a former hospital in Durham, North Carolina, and is part of the educational and scientific infrastructure that fuels the continuing economic development of the Research Triangle region. The Governors' School, however, differs considerably from a regular school, It is not run by a school board, but is under the governance of the University of North Carolina system, and its teachers are exempted from certification requirements, an innovation that has attracted many who would otherwise teach only at the college level (half of the teachers have doctorates). The school enrolls 475 juniors and seniors drawn from all over the State, though enrollment is scheduled to rise to 600 by 1991, and many of the students are residential. In the first 4 years of its operation, the school received $19 million from the State and $7 million from private sources, mainly companies. Education at the school is about four times more expensive than the average for the State, costing about $10,000 per student annually. Admission to the school is on the basis of test scores, high school grades, student essays, interviews, and home school recommendations, The school's admissions committee pays particular attention to ensuring a gender, racial, ethnic, and geographic balance of its enrollment. In 1984, 47 percent of those enrolled were female and 16 percent were Black, Hispanic, or Native American.

The school stresses individual inquiry and group cooperation, Its goal is to enrich the traditional high school curriculum rather than accelerate it. The school particularly encourages students to become involved in research at nearby Duke University in Durham, the University of North Carolina in Chapel Hill, North Carolina State University in Raleigh, and with firms at Research Triangle Park.[2] More than 4,000 teachers from other schools in the State have participated in teacher training workshops held at the school. Such cooperation is valuable because the other schools in North Carolina are not nearly so lavish as the Governor's . School and have not had much attention devoted to them.

2. Kansas City, Missouri, Magnet Schools

The public schools in Kansas City, Missouri, have recently announced plans to implement, by 1992, what some have described as "the most comprehensive magnet school court order in history, " under which all secondary and half of all elementary schools would be designated magnet schools.[3] The Kansas City school system currently enrolls 36,000 students, of which 62 percent are BIack and 6 percent are other minorities. This program of extensive magnet schools has followed long and messy court litigations that have reached the Supreme Court twice, involving the surrounding suburban school systems, the State of Missouri, and a multitude of parents along the way. The program's costs are estimated at $196 million over 6 years, part of which will be borne by Federal funds, and part by increased State and local taxation.[4]

The basis of the magnet program now being implemented is that students can follow the same theme from grade 1 to grade 12, with more choice of themes being offered at the higher grades. The themes range from the conventional ones of science and mathematics, computers, and visual and performing arts, to environmental science, engineering technology, health professions, law and public service, the military, Latin grammar, and classical Greek.

The Kansas City magnet school program is the most ambitious, and potentially most exciting, in the country. Those who will implement it face many problems, including those of funding, renovating buildings, overcoming considerable local and political suspicion, and finding enough teachers. For example, attempts have already been made to bring in teachers with the requisite skills from Belgium.

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*Quoted in *Education Week*, June 24, 19S7, p. c24. Also see Charles R. Eilber, "The North Carolina School of Science and Mathematics," *Phi Delta Kappan*, June 1987, pp. 773-777.

[2]It is not clear what relationship, if any, North Carolina Central University, a historically Black institution located in Durham, has with the School of Mathematics and Science.

[3]The following is based on Phale D. Hale and Daniel Levine, "The Most Comprehensive Magnet School Court Order in History: It's Happening in Kansas City, " presented at the Fifth International Conference on Magnet Schools, Rochester, NY, May 4, 1987.

[4]Tom Mirga and William Snider, "Missouri Judge Sets Steep Tax Hikes for Desegregation Plan," *Education Week*, Sept. 23, 1987.

Some large city school systems have had intensive science and mathematics schools for many years; examples are New York City, Chicago, and Milwaukee. One of the best known is the Bronx High School of Science in New York City. These schools were founded in the early years of this century, when publicly funded high schools were a novelty, and were strongly prevocational in nature. These schools have strong national reputations for the quality of their programs and the distinguished scientists and engineers among their alumni. Each is publicly supported alongside regular schools in the same district."

These schools offer a broader range of courses in mathematics and science than regular schools and normally are far better equipped. Laboratory work is a regular feature of courses, and, often, the schools have good linkages to local firms and research laboratories. These linkages help provide equipment, mentors, and, for some students, opportunities for participation in research. Teachers at these schools are often freed by school boards from many of the regular constraints on curriculum, and can work together with their colleagues to devise more coherent sequences of material than are customarily used. And, because students are generally enthusiastic and talented, teachers are keen to teach in these schools. In addition to science and mathematics, students take the other subjects they would take in a regular school.

A new organization, the National Consortium of Specialized Schools in Mathematics, Science, and Technology, was established in April 1988 to share experiences among and represent science-intensive schools. The initial meeting of the consortium included **27** schools, and more have joined since. The consortium is planning meetings for both students and faculty in science-intensive schools.[16]

Magnet schools differ from the other two types of science-intensive schools in that their primary goal is to promote racial desegregation rather than science education. Such schools, which normally have a predominantly minority enrollment, offer enhanced programs of instruction in particular areas or "themes" designed to draw students from a range of racial and ethnic backgrounds. Popular themes include emphases on particular subject areas, such as science and mathematics; on teaching methods, such as Montessori programs; or on educational outcomes, such as concentration on "the basics" or preparation for college attendance. Magnet school programs have become a popular alternative to forced busing, and have grown in number from none **20** years ago to over **1,000** today .*7

Magnet School Issues

Since the original objective of promoting racial desegregation has largely been achieved, magnet schools are now rapidly evolving with the trend toward increased choice in public education. The concept of "schools of choice" is now an important force in education. School districts that employ magnets are realizing that all their schools never were the same; each has its own culture and interests. Rather than maintaining uniformity, the concern is to develop schools of different specialties and emphases and to capitalize on the special advantages of each school and community .18

"Because of the novelty of most of these schools, data on the eventual fates of their graduates are not yet available. The city science-intensive schools also have surprisingly little systematic information on their graduates. One study, conducted 20 years ago by the Bronx High School of Science, is rumored to have shown that 98 percent of its students go on to college, with less than half majoring in science or engineering. One thing is certain: only a tiny percentage of each State's high school students attend such schools. This, of course, raises questions of costs and benefits to all—students, teachers, and "regular" schools—who are part of a school system that includes a special school.

*'The consortium is currently headquartered at the Illinois Mathematics and Science Academy, Aurora, IL.

[17]There are no current data on the number of magnet schools nationally. A 1983 survey put the number at about 1,100, of which about 25 percent had a mathematics or science theme. The magnet programs are located in more than 130 of the largest urban school districts. See Rolf K. Blank et al., ***Survey of Magnet Schools: Analyzing a Model for Quality Integrated Education,*** contractor report to the U.S. Department of Education (Washington, DC: James H. Lowry & Associates, September 1983). For a survey of magnet schools see Editorial Research Reports, *Magnet Schools,* vol. 1, No. 18., May 15, 1987.

'*education Week*, "The Call for Choice: Competition in the Educational Marketplace, " vol. 6, No. 39, June 24, 1987, supplement.

Magnet schools raise many issues. Among them are whether the introduction of such schools creates a two-class school system—magnet and nonmagnet. Magnet schools are also, on average, more expensive to run than nonmagnet schools. Another issue is the potential drain of talented students and teachers from the rest of the school system. Since local politics and school organizations vary so considerably nationwide, there are no simple rules for resolving these issues.

The school district's choice of admissions system to magnet programs is especially important. In Philadelphia, for example, the reliance placed on admissions tests by the magnet schools has been controversial because of its adverse effects on Black and Hispanic students. Alternatives to achievement test scores as the method of admission include home school recommendations, lotteries, and queues. The latter two methods are becoming increasingly popular.

Almost universally, students and parents cite the choices that they are given in magnet systems as inspiring them to have higher expectations of public education than they had before. Higher expectations should lead to better performance. There is some evidence, however, that while magnet programs improve the quality of education in schools or school districts with a high minority enrollment, minority students are sometimes less likely than white students to be admitted to magnet programs. This is because magnet programs are generally designed to draw white students into predominantly minority schools, the goal being an enrollment that better reflects the racial and ethnic composition of the school district. In some cases, limits have been put on minority enrollment so that the composition targets for the school can be met. Such limits can reduce, in the end, the access of minority students to magnet programs.[19]

From a public policy perspective, magnet schools are promising but unproven. They are designed to promote the goals of equity and excellence simultaneously, at somewhat increased cost. Anxieties about the cultivation of elites seem largely to have been diffused in most working magnet systems. Superintendents, administrators, principals, and teachers report enjoying working in magnet schools, and the magnet schools are effective mechanisms for minority advancement. The key is that magnet schools move the burden of rules, monitoring, certification, and control from administrators, school boards, and States to teachers and principals.[20] This enthusiasm, however, must be tempered by another realization: in many school districts, students do not even have the opportunity to learn science in elementary school. In addition, most schools *face* a serious shortage of equipment for teaching science, as well as cutbacks in resources available for offering "wet" laboratories in high schools. In short, the existence of magnet schools is no panacea to the problem **of** making a sequence of science and mathematics instruction accessible to more students.

Programs for Gifted and Talented Students

An increasing number of States and school districts are making special provisions for students they consider to be especially "gifted and talented. " Twenty-three States now mandate such provisions, and more are considering such a policy. State spending on such provisions is rising.[21]

[19]Eugene C. Royster et al., ***Magnet Schools and Desegregation: Study of the Emergency*** School *Aid Act Magnet School Program,* contractor report to the U.S. Department of Education (Cambridge, MA: Abt Associates, Inc., July 1979).

[20]Linda M. McNeil, "Exit, Voice and Community: Magnet Teachers' Responses to Standardization, " *Educational Policy,* vol. 1, No. 1, 1987, pp. 93-113.

[21]The Council of State Directors of Programs for the Gifted, "The 1987 State of the States' Gifted and Talented Education Report, " mimeo, 1987, lists State programs in some detail. In addition, the Council for Exceptional Children estimates that 15 States have special certification requirements for teachers of the gifted and talented. State and local expenditures have increased and are now about $384 million (about $150 per gifted and talented child). See Council for Exceptional Children and the Association for the Gifted, testimony before the House Subcommittee on Elementary, Secondary, and Vocational Education of the Committee on Education and Labor, on H.R. 3263, The Gifted and Talented Children and Youth Act of 1985, May 6, 1986. Industry is also becoming more active, for example, through mentor programs. Gifted and talented programs are quite common in other countries where nurturing the best minds and talents is defined as a necessity. See Bruce M. Mitchell

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These programs cover all subjects, including performing arts, languages, mathematics, and science. Nevertheless, the provision of programs for these students remains controversial for two reasons: the difficulty of defining criteria for identifying giftedness and talentedness, and the equity and social implications of giving these students special treatment.

While it is to be anticipated that the ranks of the gifted and talented are especially productive of future scientists and engineers, there are no data on the number of such students that eventually major in science and engineering. The Council of Exceptional Children, an advocate for gifted and talented education (as well as special education of the learning disabled and handicapped), estimates that there are about **2.5** million gifted and talented students nationally, or about 5 percent of all students. Other estimates put the number **at 5 million**.[22]

There is little consensus nationally on the characteristics of the gifted and talented. Standardized multiple-choice intelligence and achievement tests are widely used to sort students; those who score above threshold values on these tests are admitted to gifted and talented programs. Because of heavy reliance on such tests, there is some suggestion that labeling is prone to cultural, class, and racial bias. The process of labeling as gifted and talented does not appear to be color-blind; it has been estimated that only **13 percent of the gifted and talented are Black and Hispanic students, whereas about 25 percent of all** school students are Black and Hispanic. As a result of these possible biases and of differing cutoffs and definitions of gifted and talented, the proportion of each State's school-age population labeled as gifted and talented varies considerably. One study took 18 commonly used criteria for giftedness and found that, when applied to fifth-grade suburban Minneapolis classes, **92** percent of the students could be labeled gifted in some way.[23]

The basic issue in identifying the gifted and talented is whether individuals so labeled should merely have demonstrated good progress and high achievement in schoolwork or whether they should have some truly extraordinary skills that may be undeveloped or unexpressed. Critics of gifted and talented programs suggest that most programs merely identify those who have done well in the existing system of education. In other words, the existing intelligence and achievement tests measure only a limited range of the "gifts" and "talents."

Both proponents and opponents of special provisions for the gifted and talented agree that other dimensions besides "intelligence" and "achievement" should be explored and used. Such dimensions might also include intellectual, creative, artistic, leadership, and physical and athletic abilities. Techniques for labeling need to address each of these domains separately.[24] Some States, such as Illinois and Mississippi, are making special attempts to bring students with different strengths into gifted and talented programs.

Even if there were agreement on what gifted and talented means, the provision of special programs is politically and socially contentious. Proponents of special provisions for the gifted and talented rely on a conviction that such students possess extraordinary talents not possessed by the entire population, and that these talents should be developed to the fullest possible extent. Opponents consider the creation of such programs to be elitist in nature, in practice serving the middle and upper class students almost exclusively.

Federal support for gifted and talented education programs is provided under Chapter 2 of the Education Consolidation and Improvement Act. One estimate suggests, however, that only about 20 percent of school districts use any of their

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and William G. Williams, "Education of the Gifted and Talented in the World Community," *Phi Delta Kappan*, March 1987, pp. 531-534.

[22] Definitions of "gifted," "talented," and "special" students tend to fluctuate with the annual amounts of Federal and State funding available in these categories. This is also why a demographic bulge in a particular grade will disqualify students from "GT" (gifted and talented) classes that they took in the previous grade. The criteria are arbitrary, but their interpretation (e.g., all those in the nth percentile and above) is often rigid.

[23] Lauren A. Sosniak, "Gifted Education Boondoggles: A Few Bad Apples or a Rotten Bushel," *Phi Delta Kappan*, vol. 68, March 1987, pp. 535-538.

[24] Robert J Sternberg and Janet E. Davidson (eds.), *Conceptions of Giftedness* (Cambridge, England: Cambridge University Press, 1986); and Howard Gardner, "Developing the Spectrum of Human Intelligence," *Harvard Educational Review*, vol. 57, No. 2, 1987, pp. 187-193.

Chapter 2 funds for gifted and talented education.[25] Several bills introduced in the I00th Congress were designed to fund model programs for educating the gifted and talented, training the teachers of such students, and expanding research on gifted education.

The Department of Education's Office of the Gifted and Talented was disbanded in 1981. There are calls for its reinstatement to ". . . carefully coordinate the use of limited federal resources and to provide a much needed focal point of national leadership.''" The recent reauthorization of Federal education programs includes a provision requiring the Department of Education to set up a National Center for Research and Development in the Education of Gifted and Talented Children and Youth." Center proponents argue that Federal support has a catalytic role vis-a-vis States and school districts, and that the current reform movement has neglected the gifted and talented in favor of the mainstream and learning disabled.

The Council for Exceptional Children estimates that only one-half of gifted and talented students receive any kind of special assistance, and that such assistance itself is limited so that most gifted and talented students still spend substantial portions of time mainstreamed in ordinary classes. The Council estimates that about $400 million nationally is spent each year on such special assistance, but only about $10 million of Chapter 2 funds are spent on such programs. Some support also comes from Title II of the Education for Economic Security Act. Some of this funding has been spent on science-intensive schools, such as the North Carolina School of Science and Mathematics, which is sometimes included under the rubric of "gifted" education. Proponents argue that this funding, even though it is increasing, is still too little. There is, however, increasing interest within the private sector in such programs. In addition, several university-based programs, such as those at Johns Hopkins, Ohio State, and Duke, identify talented individuals, including those in mathematics and science, and provide enrichment programs for them during the summer.

Given that gifted and talented children have been identified and that special provision will be made for them, the basic educational issue is this: whether gifted and talented programs should focus on enriching students' exposure to the existing curriculum or encouraging them to accelerate their progress through that program so that they complete the traditional sequences of high school courses a year or two early. A related debate concerns whether students should receive enrichment or accelerated classes in all subject areas or only in single subjects, such as mathematics. A final issue is whether such focused instruction should be provided in dedicated "special" schools, or as an adjunct to the regular school curriculum.

For able students stifled in the conventional, slow-moving educational system, gifted and talented classes can provide relief and progress suited to their intellectual and emotional needs. Such classes can also help keep such students in school; many of those who drop out of school are bored, but gifted, children. The basic argument for special treatment of the gifted and talented is that without it these students would be ignored or unchallenged by the existing school system.

[25]Ellen Flax, "Economic Concerns Aiding Programs for Gifted, " *Education Week*, vol. 6, No. 33, May 13, 1987, pp. 1, 17.

[26]Ibid. Also see The Council for Exceptional Children and the Association for the Gifted, testimony before the Senate Subcommittee on Education, Arts, and Humanities of the Committee on Labor and Human Resources, on Reauthorization of Chapter 2 of the Education Consolidation and Improvement Act, July 16, 1987, p. 7.

[27]Public Law 100-297, "Conference Report to Accompany H.R. 5," Report 100-567, April 1988, p. 115.

CLOSING THOUGHTS: A LARGER MENU?

The debate over gifted and talented students begs very different questions about educational methods than the debate over alternative learning styles. The problem addressed by educators concerning different learning modes is the negative reinforcement and frustration many otherwise talented people experience in the traditional classroom. In mathematics and science learning, this has tended especially to be the case with women, and racial and ethnic minorities. The teacher of gifted and talented students faces a different problem. These students have already demonstrated some proficiency or success in the present system; the educator's task is to sustain student interest and progress.

Both issues have similar implications for science and mathematics education: How can more students be successful in science and mathematics? What does it mean to be talented in science or mathematics? How should such talent first be identified, and then nurtured? Are special schools or programs needed? Will innovative curricula that reflect new insights into how students learn —and how different their learning styles may be—spark the interest and fulfill the potential that teachers and parents often recognize in their children? Will new thinking about learning penetrate the schools? Will it be effective in "calling" more students to science and mathematics, helping them fulfill expectations (rather than ill-founded prophecies), while propelling them to the next educational stage and, ultimately, a career in science and engineering?

These questions reflect high expectations for science and mathematics education. Indeed, this chapter has glimpsed a larger menu of issues, needs, and signs of progress.