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Predictors of High Academic Achievement in Mathematics and Science by Mathematically Talented Students: A Longitudinal Study

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Educational experiences of a cohort of 1,247 mathematically talented youths (initially identified in 7th/8th grade by the Study of Mathematically Precocious Youth) were analyzed after high school and after college to identify factors correlated with high and low academic achievement in math and science in college by students with extremely high ability. Almost all students had achieved highly by conventional standards (e.g., 85% had received bachelor's degrees). Using a quantitative definition of academic achievement in college, we found that 22% were high academic achievers and 8% were low academic achievers in math and science. Variables predictive of high academic achievement (in order of strength) were precollege curricula or experiences in math and sciences, family characteristics and educational support variables, attitudes toward math and science, and differences in aptitude.

The disappointing performance of the average American student in mathematics and science has recently received considerable publicity. American children scored poorly on standardized tests when compared with children from most other nations, especially Japan (e.g., Comber & Keeves, 1973; McKnight et al., 1987; Stevenson, Lee, & Stigler, 1986; Stevenson et al., 1985). This has led several national organizations to formulate reports citing shortcomings in the quality of American education (e.g., American Association for the Advancement of Science, 1982; National Commission on Excellence in Education, 1983; National Science Board, 1983). These findings also have stimulated research to discover factors associated with high achievement in science (National Science Foundation, 1983; U.S. Department of Education, 1987).

Various suggestions have been put forth for increasing the effectiveness of American schools, and Walberg (1984) has identified nine factors that can enhance the productivity of our schools. Because these productivity factors exist, and because cross-cultural differences in mathematics performance emerge before kindergarten (Stevenson et al., 1985), early environmental manipulations may have especially strong impact on subsequent achievement. Uttal, Lummis, and Stevenson (1988) found that they do, and they also found that environmental factors operate similarly among different cultures. Moreover, they and Stevenson et al. (1985), in contrast to Lynn (1982), found that intellectual ability did not account for the cross-cultural differences in performance.

Individuals with the most potential for high academic achievement in mathematics and science (termed sciences in this article) are generally considered to be those students who represent the top few centiles in ability, especially mathematical ability (Davis, 1965; Walberg, Strykowski, Rovai, & Hung, 1984; Werts, 1967). Kuhn (1962) noted that an overwhelming majority of "scientific revolutions" can be ascribed to the work of mathematically brilliant individuals; Krutetskii (1976) found that "the development of the sciences has been characterized recently by a tendency for them to become more mathematical.... Mathematical methods and mathematical style are penetrating everywhere" (p. 6). If the educational experiences of our mathematically talented children do not maximize their potential, the United States will lose an important resource (Horowitz & O'Brien, 1986; Mumford & Gustafson, 1988). Moreover, our increasingly technological society requires many well-trained scientists. Currently, however, many potential scientists are lost to business, and a serious future shortage of scientists is anticipated (National Science Board, 1982; Office of Technology Assessment, 1988).

A long-term goal of the Study of Mathematically Precocious Youth (SMPY) is to identify the factors that lead to creative work and/or high achievement in the sciences. Most research on factors affecting science achievement has been conducted with average-ability subjects. The factors that enhance achievement by mathematically talented students, however, may be quite different from those identified for the general population (Benbow, 1988). In this article we identify factors predictive of high academic achievement in science during college by the mathematically talented. These factors may be of special importance. Even though the United States has fared poorly in cross-cultural comparisons of mathematics and science achievements for its general population, our most gifted students have ranked extremely high in international competitions (Brody, 1988; Stanley, 1987).

SMPY's working hypothesis is that high "mathematical reasoning ability" (defined here in a narrow sense as SAT-Mathematics score at age 12) that also is developed through appropriate educational opportunities (advanced and enriching course work, special programs, etc.) is the primary factor associated with high academic achievement in the sciences. Although this hypothesis is simplistic, it is easily testable and workable for the practitioner (Wallach, 1978). Moreover, this

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hypothesis is a specific formulation of Zuckerman's (1977) concept of cumulative educational advantage, which was invoked in the "formation" of Nobel laureates.

We selected intellectual ability as a primary component of our hypothesis. Although few view giftedness as one unified dimension (e.g., Gardner, 1983; Marland, 1972; Renzulli, 1978; Sternberg & Davidson, 1986), several researchers (i.e., Cox, 1926; Roe, 1953; Walberg, Rasher, & Hase, 1978) have suggested that a minimum IQ of 145 to 155 is probably necessary for eminence (Albert & Runco, 1986). Because high levels of intelligence serve as a "floor effect" (Walberg, 1988), our hypothesis predicted that ability would not be an important predictor of relative academic achievement in the sciences in college within our intellectually talented group. Yet our hypothesis also predicted that as a group, our mathematically talented students would achieve highly.

Ability, however defined, is only part of our hypothesis. As Gruber (1986) suggested, it takes much time (and sustained effort; Wallach, 1985) to create a great work, which includes time for practice, time to master domains of knowledge, and time for movement through stages and levels of a domain (Bamberger, 1986; Feldman, 1986), for "crystallizing experiences" to occur (Walters & Gardner, 1986) and for integration and reorganization of cognitive structures (Mumford & Gustafson, 1988). Furthermore, early career developments are necessary to provide talented individuals with a firm grasp of the field's existing understandings as well as with the ability to identify significant problems within its framework (Chi, Feltovich, & Glaser, 1981; Zuckerman, 1983). This takes time, too. Even more important, attainment of these developmental steps is dependent upon the talented individual's receiving appropriate educational training. Unfortunately, because of social barriers, opportunity structures may not be open to all. Yet, providing these opportunities and the facilitating environments discussed by Mumford and Gustafson (1988)—especially in cases in which they do not exist—was one of the major purposes for the establishment of SMPY.

Therefore, educational experiences are the second critical component of our hypothesis. Giftedness, regardless of its nature, involves movement through stages of a domain and is domain specific (Feldman, 1986; Gardner, 1983). Appropriate educational experiences augment the time and sustained effort required for this movement. Our hypothesis predicts that the educational backgrounds in our group of high achievers in the sciences will be richer than among our low achievers.

We do not believe that ability or schooling variables by themselves are sufficient to produce high academic achievement. We postulate that, although considered of lesser importance, attitudes, personality, family characteristics, and special interventions also play a part. A host of studies (e.g., Bloom, 1985; Feldman, 1986; Fowler, 1981; Goertzel & Goertzel, 1962; Helson & Crutchfield, 1970; Roe, 1953; Terman, 1954; Zuckerman, 1977) have detailed the importance of family influences for the development of eminence (Mumford & Gustafson, 1988). Individuals who make creative contributions come from homes with favorable backgrounds for the development of intellectual abilities and for instilling intellectual values. Although the association of birth order with cognitive performance has been shown to be an artifact of statistical sampling (Ernst & Angst, 1983), eminent individuals nonetheless tend to be first-born and to come from small families (e.g., Roe, 1953). Moreover, Albert and Runco (1986) have reaffirmed the importance of family factors in the transformation of talent into eminence. The family focuses and mobilizes the individual and the surrounding environment, thus contributing to the eventual display of talent. Our own research has underscored the importance of family attributes in the development of talent (e.g., Benbow, 1986; Raymond & Benbow, 1986). We therefore predict that high achievement is associated with family background characteristics, such as parental education and encouragement.

Personality characteristics also are important for achievement. Personality characteristics, such as intellectual and artistic values, breadth of interests, attraction to complexity, high energy, concern with work and achievement, independence of judgment, autonomy, intuition, self-confidence, ability to tolerate and resolve conflict, and creative self-image, are related to creative achievement in the sciences (Albaum, 1976; Albaum & Baker, 1977; Chambers, 1964; Gough, 1979; Owens, 1969; Roe, 1953). These traits typify SMPY's mathematically precocious students (e.g., Benbow, 1983; Fox & Denham, 1974; Haier & Denham, 1976; Keating, 1976; Weiss, Haier, & Keating, 1974). Attitudes also are important for high achievement (e.g., Meece, Parsons, Kaczala, Goff, & Futterman, 1982). For example, eminent scientists often showed early interest in science (e.g., Eiduson, 1962; Roe, 1953; Zuckerman, 1977). Although personality data were not available for most students in this study, information was obtained about their attitudes at three time points. We predicted that attitudes toward the sciences would be more positive for students who eventually display high academic achievement in the sciences than for those who do not.

Finally, Bloom (1985) described how a special person can usually be found in the lives of great athletes, mathematicians, and so forth, someone who sparked interest in a subject and then helped develop it. Is there such a special mentor in the lives of our high academic achievers in the sciences?

Study of Mathematically Precocious Youth (SMPY)

The intellectually talented students used in this study were identified by SMPY. SMPY pioneered the use of the College Board Scholastic Aptitude Test (SAT) with intellectually talented 12- to 13-year-olds (Keating & Stanley, 1972). Over a 12-year period, more than 10,000 preadolescents (mostly 7th graders) participated in SMPY "talent searches." SMPY's longitudinal study, located at Iowa State University, is tracking, through their adult lives, four cohorts of gifted students identified in the 1970s and 1980s.

Method

Subjects

Identification. Students in Cohort 1 of SMPY's longitudinal study were drawn from SMPY's first three talent searches (i.e., in 1972, 1973, and 1974). In those, 7th/8th graders in Maryland were eligible to participate if they had scored in the upper 5% (1972) or upper 2% (1973 and 1974) nationally on any mathematics achievement subtest. Qualified students took the College Board Scholastic Aptitude Test-Mathematics (SAT-M) and, in 1973, also the SAT-Verbal (SAT-V); both tests were designed to measure developed mathematical and verbal reasoning ability, respectively, of high school students. We have argued that the SAT is a more potent measure of reasoning for 7th/8th graders than for 11th/12th graders (Minor & Benbow, 1986; Stanley & Benbow, 1986). Although it also has been argued that the SAT should be viewed as an achievement measure for high school students, this is less true for SMPY testees. SMPY students have not been explicitly exposed to the curriculum tapped by the SAT. Most SMPY students were not familiar with algebra, yet many scored highly on SAT-M. Presumably, these scores resulted from extraordinary ability at the "analysis" level of Bloom's (1956) taxonomy.

Talent search scores of at least 390 on SAT-M or 370 on SAT-V were required for inclusion in Cohort 1 of the longitudinal study. These SAT criteria selected students who, as 7th or 8th graders, scored as well as the average high school female student, and thus provided a wide range of SAT score performance to study. Mean SAT scores in the talent search, which were grade-adjusted (see Benbow & Minor, 1986), were, for male students, 556 (SD = 73) on SAT-M and 436 (SD = 85) on SAT-V, and, for female students, 519 (SD = 59) on SAT-M and 462 (SD = 88) for SAT-V. Approximately 4 years later, in high school, the mean scores for Cohort 1 had increased to 695 (SD = 70) on SAT-M and 593 (SD = 88) on SAT-V for male students and to 650 (SD = 71) on SAT-M and 599 (SD = 89) on SAT-V for female students. Subsequent GRE (Graduate Record Examination) scores were comparable to high school SAT scores.

Characterization at time of identification by talent search. All talent search participants (100%) completed a basic background questionnaire before taking the initial SAT. The participants came from families where parents typically were highly educated, fathers held high-status jobs, and family size was above average (Benbow & Stanley, 1980; Keating, 1974). Participants held positive attitudes toward mathematics, science, and school and were already high achievers (Benbow & Stanley, 1982b). Traits of award-winning high school students in science (Walberg, 1969) characterize our talent search participants (e.g., Benbow, 1986; Brody & Benbow, 1986; Fox & Denham, 1974; Haier & Denham, 1976; Keating, 1976; Raymond & Benbow, 1986).

Procedure

Students in Cohort 1 were first surveyed after their expected date of high school graduation (91% response rate; Benbow, 1983; Benbow & Stanley, 1982a). A second follow-up survey of these same students with a 24-page printed questionnaire[1] was administered a year after their expected college graduation date (i.e., 5 years after the first follow-up). We used the same procedures as in Benbow and Stanley (1982a), except that we did not offer monetary incentives. The initial response rate to the second follow-up was 65%. Because viability of a longitudinal study depends on retaining a large proportion of the original sample, nonrespondents were surveyed by telephone with 20 critical questions. This increased the response rate to over 70%. Our sample included 786 male and 461 female students.[2]

A discriminant analysis was performed by sex to see if nonrespondents differed from respondents on the basis of talent search SAT-M score, high school SAT-M and SAT-V, college attendance, quality of college attended, parental educational levels, number of siblings, and fathers' occupational status. No statistically significant differences existed between respondents and nonrespondents.

High and Low Academic Achievers: A Definition

It was essential to have quantitative measures of high and low academic achievement to conduct statistical analyses. Students who reported attending graduate school full-time in mathematics or science or who enrolled in medical school were, therefore, defined as high academic achievers in mathematics and science. It is our premise that selective admission to graduate or medical school should be considered high academic achievement. We recognize that these criteria were arbitrary, reflects only academic achievements, and may identify some low achievers who enter nonselective schools; moreover, selected students may not subsequently prove to be high achievers. Conversely, some of the low or average academic achievers in college undoubtedly will become high achievers later in life. A total of 261 students (22.2%) met our quantitative criterion for high academic achievement. Their mean college GPA was 3.52 on a 4-point scale.

Low academic achievement in mathematics and science was even more difficult to define quantitatively. Low academic achievers were defined as only those students who majored in science but finished with a low GPA (bottom 20% of their graduating class), who dropped out of college, who never began college, or who did not complete high school. We recognize that a few students may not have had the opportunity to attend college for personal reasons, even though many fellowships are available. Subjects were not assigned to this group if they were continuing their education part-time after college graduation. A total of 95 students (8.1%) met the criteria for low academic achievement.

Statistical Analyses

Step-wise linear discriminant function analysis was the major statistical procedure used (Cooley & Lohnes, 1971; Tatsouka, 1971). This procedure analyzes an independent set of X variables, which are combined into an equation in such a way as to test the hypothesis that a profile based on the X measures resembles that of the members of category A more closely than that of Category B.

Where appropriate, all statistical tests of significance were evaluated by effect size (for means: $d = [X_1 - X_2]/sd$) indices (Cohen, 1977). We accepted a difference between the high and low academic achievement groups as being important if $p < .05$ and if the associated effect size was in the medium range, as determined by Cohen's arbitrary criteria. When all the students in Cohort 1 were studied, a more stringent significance criterion ($p < .01$) was used because of the large N.

Results

We first report results that established whether students with high SAT scores at age 12 subsequently demonstrated high academic achievement in college and if that achievement occurred in the sciences. This tests the predictive value of the SAT score at age 12.[3]

Completion of College

It was previously documented that 90% of students in Cohort 1 entered college, usually attending academically

[1] Copies of questionnaires used in this study can be obtained by writing Camilla Persson Benbow.

[2] Complete data were not available for all subjects.

[3] Technically, students were screened before being allowed to take SAT. This initial screening does not affect the number of high scores.

strong institutions (Benbow, 1983). This study shows that 85% of male students (665 out of 786) and female students (394 out of 461) subsequently received their bachelor's degree, over three times the rate of the general population (National Center for Educational Statistics, personal communication, July, 1987). Moreover, they completed college with outstanding academic records. Approximately 41% of male and 49% of female students graduated in the top 10% of their class; 2% and 5%, respectively, were valedictorians. Female students reported slightly higher grades than did male students (GPAs: 3.43 for female vs. 3.32 for male students; $t = 3.96$, $p < .001$).

Majors in College

Approximately 59% of male and 37% of female students majored in the sciences (Figure 1). Five years earlier, 62% of male and 50% of female students had intended to major in those areas (Benbow, 1983). Clearly, there was significant attrition among female students ($p < .01$). Male students chose engineering more often than did female students (25.4% vs. 7.6%), computer science (6.9% vs. 3.6%), and the physical sciences (10.3% vs. 4.3%), although there were no differences in mathematics or biology.

Postgraduate Education

Approximately 47% of the graduates continued their education beyond college (not all full-time and not all in sciences). More male than female students reported attending graduate or medical school (50% vs. 42%, $p < .01$), even though male scholastic records were weaker. The sex difference was especially large at the doctorate level, to which 37% of male and 24% of female students aspired ($p < .01$). Five years earlier, 39% of male and 36% of female students had planned to obtain doctorates, representing again considerable attrition among female students. Among students who continued their education beyond the bachelor's degree, 41% of male and 22% of female students enrolled in the sciences.

Career Goals

We classified long-range career goals according to type and area. Almost 40% of male and 26% of female students planned careers in the sciences ($p < .01$). An additional 12% of male and 18% of female students were pursuing medical careers ($p < .05$). (About 25% of male and female students were pursuing business careers.) Occupational goals were then classified into broad categories: administrative, professional and technical, research, clinical, university teaching, and others. (Less than 10% of the students' career goals were not in the first five areas.) Most male and female students (60%) aspired to administrative or professional/technical careers. They differed significantly in only one respect: male students were 1.6 times more likely than female students to choose research careers (15% vs. 9%, $p < .01$).

Special Achievements

SMPY students were explicitly asked about achievements, honors, and accomplishments during college and early grad-

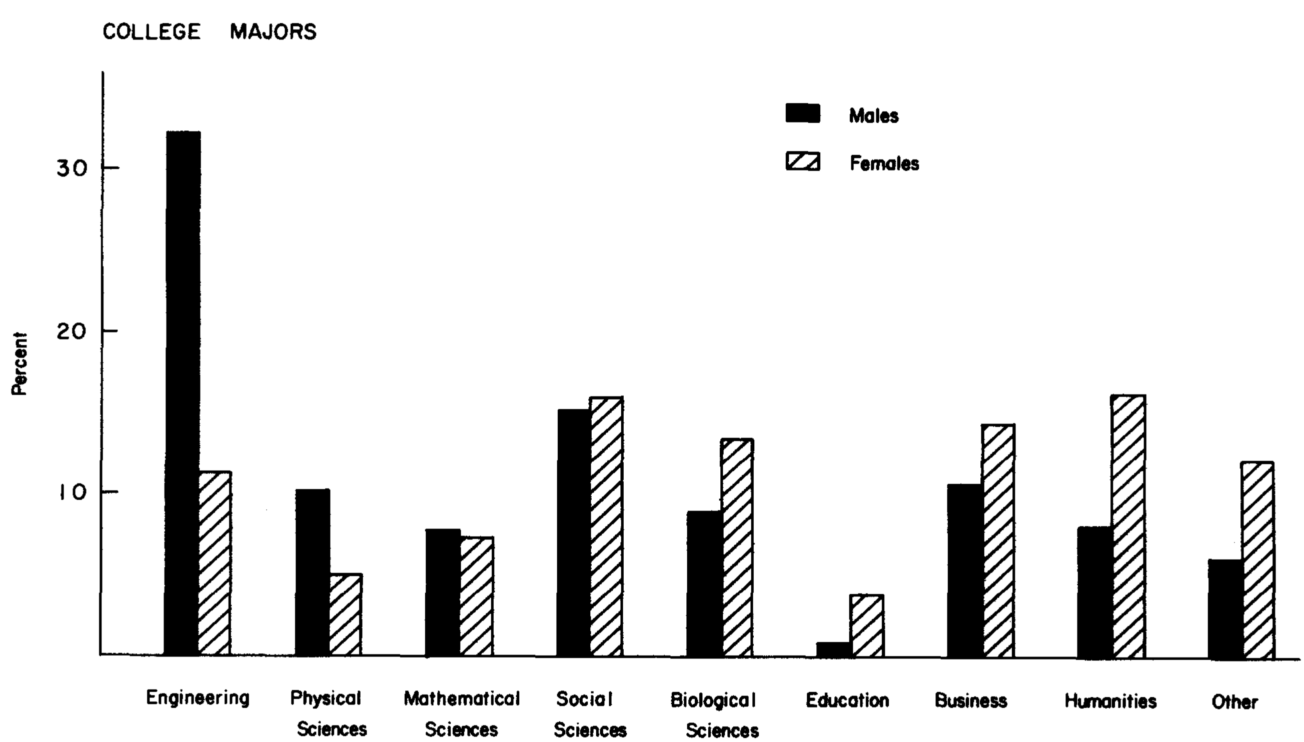

Figure 1. Reported college majors, by sex, for the mathematically talented students.

uate/medical school. In addition, they were asked whether they had ever invented something, created a new process, or any other special creative accomplishments. A large percentage of students reported special achievements (Table 1). For example, almost 10% of students reported having published a journal article or chapter, and 20% had one in preparation. Sex differences in high achievement (not all significant) favoring male students were observed in every variable except one (see Table 1).

High Versus Low Academic Achievement: Predictors

Although most students in Cohort 1 were classified as high academic achievers, a minority must be considered low academic achievers in spite of their presumed high ability. High and low academic achievers in the sciences (HAAs and LAAs, respectively) were classified as was described in the Method section. Approximately 27% and 9%, respectively, of male students met the criteria for each group, whereas 14% and 7% of female students, respectively, did. Many more male than female students were found to be HAAs in the sciences ($p < .01$). The remainder of this study deals with the identification of factors predictive of high versus low academic achievement in the sciences. (See Appendix for a list of the variables used in the study and the coding.)

Do differences in precollege curricula offered to mathematically talented students affect achievement in the sciences? Variables were the number of high school mathematics courses taken, high school science courses taken, high school and college-level mathematics and science achievement tests taken (this is an excellent measure of level of participation in mathematics and science because only the best and most motivated students take these tests and only the best high schools offer a wide variety of high-level courses in these areas), mathematics contests and science competitions participated in, Advanced Placement (AP) mathematics and science courses enrolled in, and college courses in mathematics and science taken as a high school student. For male and especially female students, differences favoring HAAs were observed for all variables (Table 2). The largest difference was found in the number of high school and college level examinations in math/science. This was followed by course-taking in mathematics and science and in the AP program. AP courses cover college-level material and are therefore rigorous and challenging for intellectually talented students in high school. Moreover, because science and especially mathematics courses tend to be sequential, course-taking discrepancies reflect differences at the higher levels of the curriculum. The results from the discriminant function analyses, which used primarily those four variables in the equation, were significant for both male and female students ($p < .001$). The canonical r was .44 for male and .58 for female students.

Do family background variables discriminate between HAAs and LAAs in the sciences? Variables studied were paternal educational level, maternal educational level, number of siblings, sibling position, and encouragement from parents (measured after college) to study mathematics, study science, attend college, and pursue career or educational goals. On all variables studied, HAAs had higher mean scores than did LAAs (see Table 2). The resulting discriminant functions were significant ($p < .001$), with canonical rs of .47 and .48

Table 1
Special Achievements and Accomplishments of SMPY Participants During College Years and First Part of Graduate School

Activity	Male students (in %)	Female students (in %)
Published		
Book	1.8	0.5
Journal article, chapter[a]	13.5	7.7
Magazine article	4.3	3.4
Newspaper article	6.6	5.0
Worked on special project in		
Math	3.7	2.6
Science	12.7	8.0
Academic awards or honors in		
Math[a]	12.8	8.0
Science	11.7	6.9
Creative accomplishment[a]	23.9	14.8
Computer program[a]	9.0	3.7
Created invention, process	11.8	7.5
Participated in contests in		
Math[a]	9.2	2.6
Science	1.6	2.1
Participated in special, honorary program in		
Math	2.3	1.0
Science	3.8	3.1
Took courses not required in		
Math[a]	52.6	42.3
Science[a]	58.7	48.3

[a] Gender difference was significant at the .01 level.

Table 2
Descriptive Statistics for Variables for High and Low Achievers by Sex

	High Achievers				Low Achievers			
	Male		Female		Male		Female	
Variable	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Family								
Paternal education	4.8	1.8	4.7	1.6	3.5	1.8	3.5	2.1
Maternal education	3.5	1.3	3.7	1.5	2.9	1.5	2.9	1.5
Occupational status	80.4	6.7	78.7	7.8	73.9	8.4	73.3	11
No. of siblings	2.3	1.5	2.4	1.4	2.4	1.6	2.3	1.4
Sibling position	1.9	1.2	2.4	1.4	2.0	1.3	2.1	1.4
Math encouragement	3.1	0.74	3.2	0.77	2.9	0.74	3.1	0.73
Science encouragement	3.1	0.75	3.2	0.72	2.8	0.77	2.9	0.79
College encouragement	3.8	0.43	3.9	0.30	3.3	0.87	3.5	0.80
Career and educational goal encouragement	3.1	0.80	3.5	0.69	2.5	0.87	2.8	0.99
Ability								
Talent search SAT-M	580	76	532	65	529	71	515	57
Talent search SAT-V	448	79	483	86	385	81	448	111
High school SAT-M	722	52	684	62	676	70	645	69
High school SAT-V	614	82	624	84	583	73	589	102
Schooling								
No. of math semesters	9.9	2.6	9.4	2.1	8.5	2.7	7.5	2.6
No. of science courses	4.3	1.3	4.2	1.2	3.6	1.6	3.3	1.2
No. of math/science tests	2.3	1.6	1.6	1.6	0.86	1.4	0.32	0.54
No. of math contests	0.72	1.4	0.49	1.3	0.11	0.44	0.35	1.6
No. of science fairs	0.31	0.73	0.19	0.43	0.23	0.53	0.19	0.48
No. of Advanced Placement math/science courses	0.89	1.1	0.51	0.80	0.30	0.79	0.06	0.25
No. of college math courses	0.17	0.52	0.02	0.14	0.02	0.13	0	0
No. of college science courses	0.12	0.40	0.07	0.26	0.04	0.19	0	0
Attitudes								
Talent search math attitude	3.6	0.60	3.2	0.72	3.4	0.71	3.3	0.55
Talent search status in math	3.1	0.66	3.0	0.56	2.7	0.61	2.7	0.66
Talent search math importance	4.5	0.64	4.4	0.67	4.4	0.83	4.3	0.73
High school biology liking	3.9	1.1	4.5	0.73	3.9	1.0	4.1	1.1
High school chemistry liking	4.1	0.98	3.8	1.1	3.9	1.0	3.7	1.2
High school math liking	4.4	0.87	4.3	1.0	4.3	0.86	4.3	1.1
High school physics liking	4.0	1.1	3.7	1.2	3.8	1.1	3.3	1.2
Math/science career	1.2	0.87	1.4	0.85	1.1	1.1	0.74	1.0
Math confidence	3.2	0.87	3.0	0.83	3.2	0.83	2.9	0.98
Science confidence	3.3	0.74	2.9	0.84	2.7	0.81	2.3	0.99
Math ease	2.9	0.99	2.6	0.97	3.1	0.86	2.9	0.79
Science ease	2.9	0.92	2.6	0.89	2.8	0.91	2.3	0.99
Math interesting	3.1	1.0	3.1	0.92	3.0	1.1	3.1	1.1
Science interesting	3.7	0.57	3.7	0.48	3.4	0.76	3.0	1.2
Math importance	2.3	0.83	2.4	0.75	2.3	0.82	2.0	0.85
Science importance	2.8	0.57	2.6	0.76	1.9	1.1	1.7	1.2
Interventions (in %)								
Positive person/event	45		53		28		60	
Negative person/event	12		02		15		20	
Science training program	07		22		11		05	
Math training program	30		30		29		06	

for male and female students, respectively. The most powerful variables in the discriminant function were encouragement to attend college and to pursue career and educational goals and paternal educational level. Surprisingly, there was only a small difference between HAAs and LAAs on encouragement to study mathematics (effect size, $d = .2$) and only a moderate one for studying science (effect size, $d = .4$).

Are attitudinal variables associated with high academic achievement in the sciences? Before talent search participation, there were essentially no differences between HAAs and LAAs in their attitude toward mathematics for either male or female students (Table 2). Yet, high achievers ranked their standing within their mathematics class more highly than did low achievers ($d = .57$). By the end of high school, differences began to emerge in attitudes, especially for girls and in science. Variables studied were liking for mathematics, biology, chemistry, and physics and consideration of a career in those areas. The effect sizes for differences between male HAAs and LAAs ranged from 0 to .17, not even small by Cohen's (1977) criteria. For female students, the range was from .05 to .63, which indicated some substantial differences in attitudes. When we computed discriminant analyses by sex with high school data, the resulting discriminant function was significant for female ($p < .001$) but not male students. The canonical *r*s were .07 and .39, respectively for male and female students. For female students, the most powerful discriminating variable was having considered a career in math/sciences.

At the end of college, several measures of attitude toward mathematics and science were available (Table 2). The resulting discriminant functions were significant for male and female students ($p < .001$), with canonical *r*s of .48 and .55, respectively. For both male and female students the most powerful variable was "how important science was for their future career." Overall, attitude toward science was a more important correlate of high academic achievement in the sciences than was attitude toward mathematics.

Is measured ability in 7th/8th grade an important predictor of later academic achievement? Talent search and high school SAT-M and SAT-V scores were studied for HAAs and LAAs (see Table 2). For male students, there was a 51-point difference ($d = .65$) favoring HAAs at the time of talent search, which remained stable during high school ($d = .78$). The effect sizes for these differences were substantial. For female students, there was a 17-point difference favoring HAAs at the time of talent search, but during high school this difference increased to 39 points (effect size, $d = .6$). Few students had talent search SAT-V scores, but the data we had suggest that for SAT-V, the differences between groups were larger in the talent search than they were for SAT-M, but they decreased somewhat by high school graduation (Table 2). We computed a discriminant analysis by sex using 8th-grade SAT-M and high school SAT-M and SAT-V. (Too few cases had 7th/8th-grade SAT-V scores to allow inclusion.) Both analyses were significant at least at the $p < .01$ level. The canonical r was .30 for male and .29 for female students. The only variable to be entered into the function, however, was high school SAT-M for both male and female students. Although the differences between HAAs and LAAs must be considered important, especially on high school SAT-M, LAAs were nonetheless extremely able. It does not seem likely, therefore, that ability differences between these two groups alone can explain more than a small part of the achievement difference between them.

Is early educational attention an important factor influencing academic success in the sciences? The answer was a weak yes for our high-ability students. The four variables studied were special academic training in mathematics and in science, as well as existence of a person or event that had a positive or separately a negative influence on their educational decisions.[4] Because all variables were dichotomous, a discriminant function was not calculated. For male students, the only significant difference was in the percentage reporting a positive influence of a person or event ($p < .05$). For female students, significant differences ($p < .05$) were seen in all variables, except the positive influence of person or event.

A Model to Identify HAAs and LAAs

After calculating the four discriminant functions by sex, we attempted to further narrow the selection of the most important variables predicting high academic achievement in the sciences. All variables meeting the criteria for entry into the discriminant functions described earlier that were predictors rather than correlates were selected as variables for another discriminant function between HAAs and LAAs. There was one exception. We used talent search SAT-M score rather than the high school score. Moreover, the family encouragement variables were measured after college graduation, but presumably reflect earlier influences. To ensure an adequate *N*, we did not calculate the discriminant function by sex. This seemed justifiable, because similar results were obtained for both male and female students, but with stronger effects for female students. In total, 18 variables were analyzed. Of those variables, 12 variables satisfied the criterion necessary for entry into the discriminant function (Table 3). This function correctly classified 83% of the students as HAAs and LAAs.

Variables representing the high school curriculum in mathematics and science dominate the equation, although these variables were not entered into the discriminant analysis first (encouragement to attend college was). Every curriculum variable was entered into the discriminant function, comprising 50% of the variables. Ability on SAT-M in talent search did not contribute much to the final function.

Discussion

This study surveyed the educational patterns of mathematically talented youth from 7th/8th grade, when they were first identified by SMPY, until a year past college graduation (10 years later). Our purpose was to identify factors predictive of

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[4] The special fast-paced academic classes pioneered by SMPY were experimental at the time Cohort 1 was identified. Because the initial classes contained small numbers of students, we cannot study their effects here. Such data can be found in Swiatek and Benbow (in press).

Table 3
Results From Final Discriminant Analysis Using All Significant Predictor Variables From the Four Separate Discriminant Analyses That Were Performed by Sex

Variables	Weights	r^a
College encouragement	.33	.56
No. of math/science exams	.59	.54
Career and educational encouragement	.51	.55
Fathers' education	.27	.47
Math encouragement	−.29	.11
No. of semesters of math	.22	.34
No. of college natural science courses in high school	.20	.15
Sibling position	.17	.02
No. of math/science AP courses	−.35	.31
No. of college math enrichment courses	.13	.18
No. of science courses	.14	.34
7th/8th grade SAT-M	.13	.37
No. of siblings		−.07
High school physics liking		.06
Considered math/science career		.05
High school chemistry liking		.05
High school biology liking		.02
High school math liking		.00

Note. Canonical $r = .57$; $\chi^2(12, N = 265) = 99.3$; $p < .001$; Wilks's lambda = .68; eigenvalue = .47.
[a] Pooled within-groups correlations between discriminating variables and canonical discriminant function.

high academic achievement in the sciences by intellectually talented students. Several conclusions can be drawn.

First, individuals classified as having high ability solely on the basis of a high SAT score at age 12 will, with very high probability, perform well academically during the subsequent decade. Moreover, self-report data suggest that SMPY students participate in activities that can lead to creative adult achievement in the sciences (see Segal, Busse, & Mansfield, 1980). Whether a talent search SAT score identifies all or even most individuals who become subsequently high academic achievers will require further study. The SAT has been attacked with regards to its validity, usefulness, and fairness to various ethnic and sex groups. Nonetheless, its predictive value for identifying at age 12 future scientists is quite remarkable: 52% of all male and 44% of all female students were pursuing scientific/medical careers 10 years later.

Second, because most students in our sample had the aptitude necessary to achieve highly in the sciences in college, we identified factors predicting high or low academic achievement in those areas. Precollege curricula in mathematics and science, family characteristics and educational support variables, attitudes toward mathematics and science, and aptitude, when considered separately, all discriminated between HAAs and LAAs, but to varying degrees (listed in order of strength). When all predictor variables that were entered into the four separate discriminant functions for each gender were analyzed together, it became clear that schooling variables had the greatest effect on achievement. Family background and encouragement variables (those that instill intellectual values), however, also were important influences on high achievement, consistent with findings by Albert and Runco (1986) and Bloom (1985). Moreover, there was some evidence to suggest that, in the lives of the high achievers, there had been some person or event with a significant influence on their educational development. Ability in the 7th/8th grade was not a good predictor of subsequent high versus relatively low achievement.

A previous study of school experiences was consistent with these findings (Brody & Benbow, in press). SMPY students who had exhibited large gains during high school on SAT-M were compared with students with essentially no growth on SAT-M during that time. A similar comparison was done for SAT-V. Differences in schooling discriminated between the high- and low-growth groups. On SAT-M, the math/science curriculum was important, whereas on SAT-V, the verbally oriented curriculum was most salient. Moreover, among Cohort 1 students, the high school curriculum explained additional variance in students' high school SAT-M scores after the effect of 7th/8th grade scores had been accounted for.

Differences in school programs appear to have a profound effect on levels of ability and achievement, even among the intellectually talented. Thus, our data support the concept of intervention. Intellectually talented students will not achieve as highly if not provided with appropriate educational opportunities. This contradicts conventional wisdom that intellectually talented students make it on their own.

There were essentially no attitudinal differences in the area of mathematics between HAAs and LAAs in any of the three surveys. Differences in attitudes were found in science, and these differences and their relation to achievement appeared to become larger between high school and college graduation. Science attitudes and academic achievement in mathematics and science seem to be coordinated.

Sex differences in achievement in the sciences in college were consistently found. They appeared to be greater after college than they had been in high school (see Benbow & Stanley, 1982a). It is of considerable topical interest, however, that all the "environmental" variables were better at separating HAAs and LAAs among female than among male students ($p < .05$ by a sign test). Yet the process or types of relations appeared to be about the same for male and female students. Our data suggest, therefore, that educational facilitation appears to be especially important for high female-student achievement. This indicates that intervention may ameliorate some of the sex differences in achievement.

Moreover, the educational aspirations of SMPY females declined significantly during the college years. Attrition also was significant in the numbers majoring in the sciences. This represents a loss of human resources and should be of national concern. We are investigating this aspect further (Albright, 1989), with results that highlight the importance of the high school curriculum.

Although we had postulated that environmental variables might influence achievement differently for the intellectually talented relative to those of average ability, we found no evidence to support that view. Our findings are predicted by models put forth by Meece et al. (1982) and others and are consistent with Walberg (1984) and Maehr (1986). This does not imply, however, that the same schooling experiences are appropriate for the intellectually talented as for average-ability students. Schooling experiences specifically designed for able students were best able to discriminate between the high and low achievers in this study. Moreover, the high achievers had more frequently participated in special mathematics or science programs.

The data in this study strongly support our working hypothesis that "high ability" that is stimulated through special opportunities is the single most important factor associated with high academic achievement in the sciences (for further evidence on this point, see, e.g., Bartkovich & Mezynski, 1981; Benbow, Perkins, & Stanley, 1983; and Brody & Benbow, 1987). Our results highlighted the importance of both high ability and educational experiences. Both interact to produce subsequent high academic achievement in the sciences. Our results also suggest that family characteristics had predictive value. These need to be included more explicitly in our hypothesis.

It should be emphasized that we have only examined academic achievement in college. We do not know how academic achievement translates into creative adult accomplishments. Csikszentmihalyi and Robinson (1986) have distinguished between presented problem solving (as usually done in class work) and discovered problem finding in the creative process. Although Gowan (1977) defined intellectual talent as the potential to become creative, Gruber (1982) has shown that intellectually talented children do not necessarily grow up to be creative adults and that creative adults were not necessarily intellectually talented children. The SMPY longitudinal investigations, which are designed to span 50 years, should ultimately provide data to address these issues (Horowitz & O'Brien, 1986).

It would now be useful to know (a) what specific aspects in the precollege curriculum have the most long-lasting effects on achievement in the sciences, (b) what factors in the curriculum enhance the development of the abilities measured by the SAT, and (c) what factors are synergistic in producing high academic achievement in the sciences.

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Appendix

Coding of Variables Used in the Study

Paternal and maternal educational levels (highest):
- 1 = less than high school diploma
- 2 = high school diploma
- 3 = 2 years of college
- 4 = bachelor degree
- 5 = more than college
- 6 = master degree
- 7 = doctorate

Encouragement: For studying math, for studying science, for attending college, for pursuing career and educational goals (ratings made after college):
- 0 = strong discouragement
- 1 = moderate discouragement
- 2 = neither encouragement nor discouragement
- 3 = moderate encouragement
- 4 = strong encouragement

Talent search mathematics attitude:
- 1 = strong dislike
- 2 = moderate dislike
- 3 = moderate liking
- 4 = strong liking

Talent search rating—importance of math for future career:
- 1 = not at all
- 2 = not very
- 3 = slightly
- 4 = fairly
- 5 = very

Perceived status in 7th/8th-grade math class:
- 1 = less well than most
- 2 = at class average
- 3 = better than 1 or 2
- 4 = best in class

Rated liking in high school of: Biology, chemistry, mathematics, and physics:
- 1 = strong dislike
- 2 = moderate dislike
- 3 = neutral
- 4 = moderate liking
- 5 = strong liking

Number of math/science careers considered in high school:
number
Math confidence/science confidence (after college):
0 = very anxious
1 = somewhat anxious
2 = neither confident nor anxious
3 = somewhat confident
4 = very confident
Math ease/science ease (difficulty; after college):
0 = very difficult
1 = somewhat difficult
2 = neither easy nor difficult
3 = somewhat easy
4 = very easy
Math interesting/science interesting (after college):
0 = very boring
1 = somewhat boring
2 = neither interesting nor boring
3 = somewhat interesting
4 = very interesting
Math importance/science importance (to planned career; after college):
0 = not useful
1 = a little useful
2 = moderately useful
3 = very useful

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