

Research Article

MEN AND WOMEN AT PROMISE FOR SCIENTIFIC EXCELLENCE: Similarity Not Dissimilarity

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Abstract—*U.S. math-science graduate students possessing world-class talent (368 males, 346 females) were assessed on psychological attributes and personal experiences in order to examine how their talents emerged and developed. Comparisons were made, using similar assessments, with mathematically talented students (528 males, 228 females) identified around age 13 and tracked into adulthood by the Study of Mathematically Precocious Youth (SMPY). Well before college, both samples were academically distinguished; however, the graduate students could be identified during adolescence as a subset of mathematically talented youths based on their nonintellectual attributes. Their profiles corresponded to what earlier psychological studies found to characterize distinguished (and exclusively male) scientists: exceptional quantitative reasoning abilities, relatively stronger quantitative than verbal reasoning ability, salient scientific interests and values, and, finally, persistence in seeking out opportunities to study scientific topics and develop scientific skills. On these attributes, sex differences were minimal for the graduate students (but not for the SMPY comparison groups). Developing exceptional scientific expertise apparently requires special educational experiences, but these necessary experiences are similar for the two sexes.*

Continuing discussion focuses on whether the United States is adequately training students in mathematics and science for competition in an increasingly technological workplace and global economy (Ayers, 1999; Colwell & Kelly, 1999; Committee for Economic Development, 1998; Lehrman, 1999; Levin & Stephan, 1999; National Science and Technology Council, 2000), a concern also raised in the 1950s with the launching of Sputnik. Although such concerns remain prominent, U.S. graduate programs in mathematics and science are regarded as preeminent. Students who meet the stringent hurdles for admissions into them unquestionably are seen as possessing world-class talent. In this article, we document the personal attributes and experiences that propelled U.S. students to institutions world-renowned for developing scientific leaders.

Of related contemporary interest and concern is the large ratio of males to females throughout many engineering and physical science fields (Mervis, 1999a, 1999b; Wickware, 1997). This disparity widens along the educational-occupational continuum through doctoral training and beyond. A great deal of federal money continues to be spent in an effort to close this gap, with limited success (Kleinfeld, 1998–1999; Mervis, 2000; National Science Foundation, 1999).

Constraining efforts to understand this problem is the scarcity of knowledge concerning the personal experiences and characteristics of female scientists. Many studies have examined male scientists (e.g., Jackson & Rushton, 1985; Roe, 1953; Terman, 1954; Zuckerman, 1977) and yielded some understanding of their developmental trajectories and personal characteristics. Males achieving scientific distinction typically display exceptional quantitative reasoning abilities, relatively stronger quantitative than verbal reasoning ability (or quantitative “tilt”), and strong scientific interests and values. In addition, a variety of scientific studies of world-class accomplishment and the development of expertise have found that attributes specifically indicative of indefatigable capacities for study and work (e.g., “industriousness,” “perseverance,” and “zeal”) are important to such achievement. These conative factors, which are relatively distinct from abilities and preferences, have more to do with individual differences in energy or psychological tempo and are typically conspicuous concomitants of exceptional achievement (Ericsson, 1996; Eysenck, 1995; Lubinski & Benbow, 2000; Simonton, 1988). Female scientists, however, have not been studied systematically in groups large enough for conclusions to be confidently drawn regarding their development and psychological characteristics. Researchers do not know if findings based on male samples generalize to women.

Research with mathematically talented samples has found that although male and female groups earn comparable proportions of advanced educational credentials, they differ appreciably in the academic and occupational disciplines and fields to which they aspire (Benbow, Lubinski, Shea, & Eftekhari-Sanjani, 2000). Mathematically talented women tend to be more represented in the humanities and the life and social sciences relative to engineering and the physical sciences, whereas the inverse is true for mathematically talented males. Further, sex differences in proportionate group membership across academic fields and occupations are meaningfully related to patterns of differences on ability, interest, and values dimensions (Achter, Lubinski, Benbow, & Eftekhari-Sanjani, 1999; Dawis, 1991, 1992; Dawis & Lofquist, 1984; Holland, 1997; Humphreys, Lubinski, & Yao, 1993; Tyler, 1974; Williamson, 1965). Such findings call into question how much individual choice, based on psychological characteristics, is responsible for disproportionate gender representation in the math-science pipeline (Holden, 2000). In the present study, we addressed this sensitive issue by examining both men and women who possess promise not only for scientific careers, but also for genuine scientific distinction.

For this study, male and female graduate students from some of the top math and science programs in the United States shared information regarding their educational experiences, personal views, and career objectives. Empirical evidence and theory in vocational psychology indicate that the ideal educational and occupational tracks are responsive to and build on individuals’ salient abilities and educational-vocational preferences (Dawis, 1992; Dawis & Lofquist, 1984; Tyler, 1974; Williamson, 1965). A corollary expectation derived from

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the theory of work adjustment (Dawis & Lofquist, 1984; Lofquist & Dawis, 1991), for example, anticipates group differences in educational-vocational outcomes to the extent that ability-preference profiles differ between groups. Accordingly, we also secured assessments of preferences, using well-known measures of vocational interests and values, and information regarding abilities.

Where possible, these assessments were interpreted against longitudinal data from a sample of high-ability (mathematically gifted) individuals of similar age. These data were collected by the Study of Mathematically Precocious Youth (SMPY; Lubinski & Benbow, 1994), a planned 50-year longitudinal study of more than 5,000 intellectually talented individuals recruited between 1972 and 1997 through talent-search methods. Talent searches have administered college entrance exams (e.g., the College Board Scholastic Assessment Test, or SAT) each year to, now, almost 200,000 seventh (and some eighth) graders scoring within the top 3% of ability on standardized achievement tests routinely administered by their schools (Assouline & Lupkowski-Shoplik, 1997; Cohn, 1991; Lubinski & Benbow, 1994). SMPY, instituted under the direction of Julian C. Stanley at Johns Hopkins University, was designed to uncover optimal ways of both identifying intellectually precocious individuals and fostering their academic development, with special emphasis on uncovering key antecedents to, and facilitators of, the development of mathematical and scientific talent.

In this report, we concentrate on three questions: First, how similar are the backgrounds and psychological attributes of top math-science graduate students compared with individuals identified as mathematically talented at age 13? Second, are there important sex differences among top math-science graduate students, and, if so, how do these compare with those observed in mathematically talented adolescents and young adults? Third, do future scientists have special needs that require distinct opportunities for their talent to develop optimally, and does the nature of these opportunities vary as a function of gender? Answers to these questions have implications for educational practice and public policy regarding (a) gender-equity issues and (b) the development of scientific talent necessary for maintaining competitiveness in an increasingly technological and knowledge-based society.

METHOD

Participants

Graduate students

First- and second-year graduate students (368 males, 346 females) were recruited from math and science programs ranked among the top 15 by Gourman (1989) and the National Research Council (1987). The mean age for the males was 24.5 years ($SD = 2.0$ years), and the mean age for the females was 24.8 years ($SD = 1.8$ years). Only U.S. citizens were sought, as we were primarily interested in U.S. approaches to education and talent development.

Talent-search participants

The SMPY sample consisted of mathematically talented individuals in the mid-Atlantic region (528 males, 228 females). These participants were of similar age to the graduate students but were initially identified at ages 12 to 14, between 1976 and 1979, through talent-search methods. This subset of participants in SMPY's longitudinal study represents approximately the top 0.5% of the population in general intellectual ability; furthermore, on the mathematical subtest of the SAT (SAT-M),

they all had scores of 390 or higher, which constituted the top 1% in quantitative reasoning ability for their age group. Overall, their SAT performance was comparable to that of college-bound seniors, but they took the test 4 years early (Benbow, 1988; Lubinski & Benbow, 1994).

Instruments

The graduate students completed an extensive biographical questionnaire; some of the items on this questionnaire also were contained in follow-up questionnaires completed by the talent-search participants at 5-, 10-, and 20-year intervals following their initial identification (see Benbow et al., 2000; Lubinski & Benbow, 1994). Topics covered included education, family, home experiences, and occupational goals. Standardized test scores obtained by the graduate students during their young adolescence (sometimes as participants in talent searches) and as part of their applications for admission to undergraduate and graduate schools (i.e., SAT, American College Test, Graduate Record Examination) were secured if available.¹ In addition, the Study of Values (SOV; Allport, Vernon, & Lindzey, 1970) and the research version of the Strong Vocational Interest Inventory (SVII; Harmon, Hansen, Borgen, & Hammer, 1994) were completed by the graduate students. These preference instruments also were completed by separate but representative subsets of the talent-search participants. The SVII was mailed to a subset of SMPY participants 15 years after their initial identification, whereas the SOV was included with SMPY's routine 5-year follow-up questionnaire for another subset.

The SOV is an ipsatively scaled measure of six value orientations (Aesthetic, Economic, Political, Religious, Social, and Theoretical) relevant to educational and vocational choice (Allport et al., 1970; Dawis, 1991). Means are centered at 40, with a standard deviation around 10. The test-retest stability of this instrument for intellectually talented youth has been established over a 20-year interval (age 13 to age 33; Lubinski, Schmidt, & Benbow, 1996) using another sample of SMPY participants. Because a small subset of items was considered dated or sexist, their content was modified slightly.

The General Occupational Themes of the SVII were used to measure Holland's (1997) RIASEC (Realistic, Investigative, Artistic, Social, Enterprising, and Conventional) vocational-interest themes. Means are centered at 50, with a standard deviation of 10. Holland's themes represent the most popular contemporary model of vocational interests (Day & Rounds, 1998; Lubinski, 2000). The test-retest stability (15-year) of the General Occupational Themes, as well as the Basic Interest Scales, has been demonstrated for intellectually talented youth (age 13 to age 28; Lubinski, Benbow, & Ryan, 1995), and construct validity (including incremental and predictive validity) for these and the SOV scales has been demonstrated for high-ability adolescents (Achter et al., 1999; Schmidt, Lubinski, & Benbow, 1998).

Procedure

Graduate students

In 1991 (spring), we mailed the top 15 U.S. math-science graduate training programs, by field (Gourman, 1989; National Research Council, 1987), a letter asking for permission to survey their students. For

1. A limitation of this study is that it did not include assessments of spatial ability, possibly the second most important personal attribute (after quantitative reasoning ability) for excellence in and commitment to careers in inorganic science (Humphreys, Lubinski, & Yao, 1993; Shea, Lubinski, & Benbow, in press).

each discipline, department chairs were sent our protocols and informed that these materials would take approximately 1.5 hr to complete. Because we sought to evaluate potential sex differences, we tried to obtain 50% female representation. The male:female ratio within these departments often exceeded 3:1, so we requested that as many females as possible participate, along with an equal number of randomly selected males. Departments agreeing to approach their students concerning participation were mailed packets of questionnaires in April 1992, along with \$15.00 cash for each student. The response rate was 94%.

The disciplines covered by those students who indicated their graduate concentration (with male:female sample sizes in parentheses) were aerospace engineering (5:4), biochemistry (38:41), cellular and molecular biology (11:9), chemical engineering (34:34), chemistry (98:104), civil engineering (19:12), computer science (4:6), electrical engineering (21:20), industrial engineering (19:18), mathematics (28:21), mechanical engineering (11:11), nuclear engineering (7:7), and physics (58:46). The schools that were approached and elected to participate were California Institute of Technology, Cornell University, Harvard University, Johns Hopkins University, Massachusetts Institute of Technology, New York University, Northwestern University, Princeton University, Stanford University, State University of New York-Stony Brook, University of California-Berkeley, University of California-Los Angeles, University of California-San Diego, University of Illinois, University of Michigan, University of Pennsylvania, University of Washington, University of Wisconsin, and Yale University.

Talent-search participants

For a more complete description of SMPY longitudinal procedures, see Benbow et al. (2000) and Lubinski and Benbow (1994). Response rates for the 5-, 10-, and 20-year follow-up questionnaires (without deducting from the denominator participants not contacted) were 83%, 66%, and 77%, respectively, for males and 85%, 68%, and 83%, respectively, for females. A small number of participants, 23 males (4%) and 10 females (4%), were lost track of early in the study and did not participate in any of the follow-ups. Some had died. Completing all three follow-ups were 279 males (53%) and 132 females (58%). At about age 18, 124 males and 61 females completed the SOV; this is the first report of their age-18 profile. An independent sample (114 males and 48 females) completed the SVII at about age 28; their age-28 profile was reported in Lubinski et al. (1995).

RESULTS

Abilities

To excel in math-science career tracks, individuals must have high levels of intellectual ability, especially quantitative reasoning ability. Both the graduate students and the talent-search participants had high school SAT scores that clearly manifest intellectual distinction (see Table 1). However, as impressive as these groups' mean scores are, the magnitude of their development is not fully captured because of ceiling effects, especially for the SAT-M. Ceiling effects occur when a scale's mean falls within two standard deviations of the maximum possible score (800 for both the SAT-M and the SAT-V, the verbal subtest of the SAT) and become increasingly problematic as the mean approaches the scale's upper limit. Table 1 displays statistics indicating the intensity of SAT ceiling effects. Although SAT-M ceiling effects were found for all four groups, they are particularly problematic for males (their SAT-M means are less than 1.25 standard deviations from the test's ceiling). Both groups of males earned significantly more top possible SAT-M scores than their female counterparts: for graduate students, $\chi^2(1, N = 534) = 6.79, p < .01$; for talent-search participants, $\chi^2(1, N = 546) = 15.1, p < .001$. For the SAT-V, ceiling effects were less pronounced, with no significant sex differences evident and the percentage of people with top possible scores never reaching 2% for any group. Given these findings, it is critical to take into account curtailment in the range of SAT-M scores when evaluating findings involving the SAT.

SAT profiles (SAT-M vs. SAT-V) are expected, on average, to manifest a quantitative tilt among individuals pursuing careers in math and science. Because of the ceiling effects, the degree of tilt in the present samples is somewhat underestimated. Nonetheless, we attempted to estimate the magnitude of quantitative tilt in the high school SAT scores of the males and females by comparing the differences between subtest means with the differences for male and female college-bound seniors from the same age cohort. Throughout the 1980s, the maximum mean difference between SAT-M and SAT-V scores (SAT-M – SAT-V) was 66 points for males and 33 points for females (College Entrance Examination Board, 1992). For the groups in the present study, these means (with medians in parentheses) were 92 (90) for graduate student males, 79 (70) for graduate student females, 87 (80) for talent-search males, and 31 (30) for talent-search females. Quantitative tilt does appear to characterize the graduate students of both sexes and the talent-search males, but not the talent-search females.

Table 1. Scholastic Assessment Test (SAT) statistics

Group	Mean (SD)		Assessment of ceiling effect ^a		Percentage with top possible score	
	SAT-M	SAT-V	SAT-M	SAT-V	SAT-M	SAT-V
Graduate students						
Males	718 (67)	625 (82)	1.22	2.13	8.4%	0.4%
Females	701 (64)	622 (94)	1.55	1.89	3.1%	0.0%
Talent-search participants						
Males	747 (43)	660 (74)	1.23	1.89	12.7%	1.0%
Females	705 (58)	674 (67)	1.64	1.88	1.9%	1.2%

Note. SAT-M and SAT-V refer to the mathematics and verbal subtests, respectively, of the SAT.

^aThis assessment shows the range between a group's mean and the top possible score (800) in within-group SD units.

Further, a Bonferroni multiple-comparison procedure performed on all four group means revealed no significant differences among the first three (at $\alpha = .05$), whereas talent-search females differed from all other groups (at $\alpha = .001$).

The importance of these ability patterns can be illustrated with simple percentages. For example, 75% of talent-search males and 51% of talent-search females with SAT difference scores at or beyond the median for gender-equivalent graduate students secured undergraduate math-science degrees. For talent-search participants with SAT difference scores below these medians, the male and female percentages for receiving such degrees dropped to 57% and 28%, respectively, and both decreases were significant: for males, $\chi^2(1, N = 312) = 11.20, p < .001$; for females, $\chi^2(1, N = 134) = 6.68, p < .01$. Differential ability patterns foreshadow distinct educational tracks, even among individuals with exceptional quantitative abilities in seventh grade.²

Interests and Values

Information regarding educational-vocational preferences (RIASEC and SOV) is displayed in Figure 1. Investigative interests and theoretical values are the most critical preference dimensions for identifying scientists (Allport et al., 1970; Dawis, 1991; Holland, 1997). All groups displayed marked investigative interests, but the means for the graduate students were predictably higher than those for the talent-search participants. Again, gender-equivalent group comparisons are revealing: For investigative interests, 33% of talent-search males and 21% of talent-search females scored at or beyond 60, the median for both male and female graduate students (58% of males and 51% of females among the graduate students scored 60 or higher). These gender-equivalent comparisons were significant: for males, $\chi^2(1, N = 476) = 22.7, p < .001$; for females, $\chi^2(1, N = 388) = 15.8, p < .001$.

For theoretical values, 43% of talent-search males scored at or above 49, the median for male graduate students, and 31% of talent-search females scored at or beyond 46, the median for female graduate students (among graduate students, 53% of males and 55% of females met or exceeded these respective medians). These gender-equivalent comparisons were also significant: for males, $\chi^2(1, N = 486) = 3.9, p < .05$; for females, $\chi^2(1, N = 404) = 11.3, p < .001$.

Lifestyle Preferences

Figure 2 displays findings concerning a variety of lifestyle preferences. Three preferences markedly distinguished the graduate students from the talent-search participants. First, the graduate students placed greater importance than the talent-search participants on having a good education: for males, $d = .68, t(737) = 9.2, p < .001$; for females, $d = .52, t(527) = 5.7, p < .001$. Second, the graduate students placed greater importance on having a full-time career: for males, $d = .53, t(721) = 7.1, p < .001$; for females, $d = .73, t(520) = 8.0, p < .001$. Third, they also placed greater importance on being a leader in the community: for males, $d = .36, t(735) = 4.9, p < .001$; for females, $d = .52, t(524) = 5.7, p < .001$.

In addition, although graduate student males and females did not differ significantly in the perceived importance of maintaining a full-

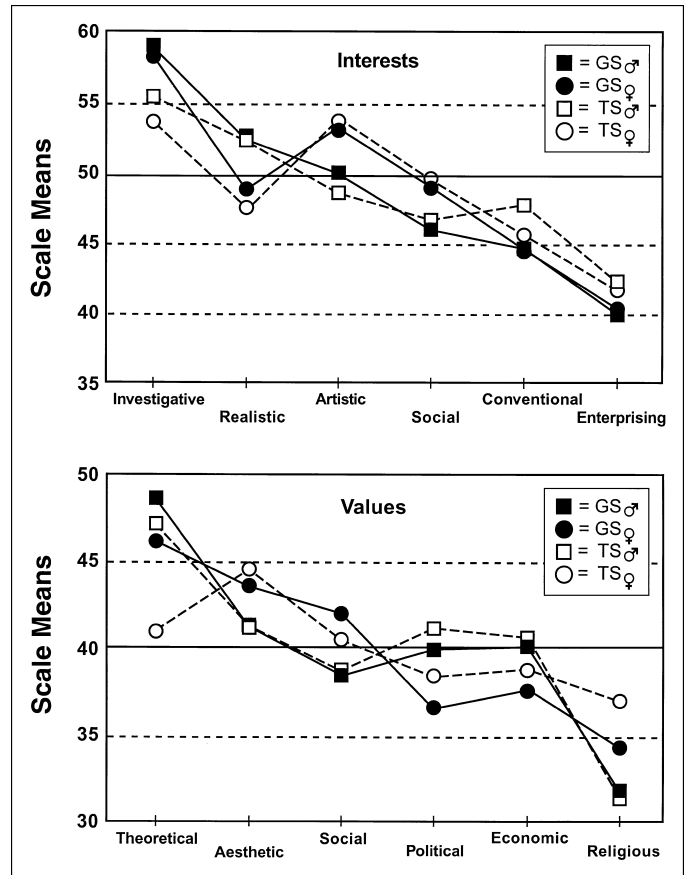


Fig. 1. Educational-vocational preferences of the graduate students (GS) and talent-search participants (TS). The top graph shows means for Holland's (1997) interest themes (Strong Vocational Interest Inventory; Hansen & Campbell, 1985), and the bottom graph shows means for Allport, Vernon, and Lindzey's (1970) Study of Values. Group *n*s for the interests and values inventories, respectively, were 362 and 362 for GS males, 340 and 343 for GS females, 114 and 124 for TS males, and 48 and 61 for TS females.

time career (77% of the females and 81% of the males reported this was "important" or "extremely important"), significant differences did emerge in the perceived importance of having a part-time career for some time period and having a part-time career always, $\chi^2(1, N = 652) = 84.9, p < .001$, and $\chi^2(1, N = 659) = 28.4, p < .001$, respectively. In regard to working part-time for a limited period of time, about one third (31%) of graduate student females responded that this option was "important" or "extremely important," compared with 9% of graduate student males. For having a part-time career always, the respective proportions were 19% for females and 9% for males.

Educational Experiences

The four groups revealed exceptional and remarkably similar educational backgrounds. Both the graduate students and the talent-search participants tended to have taken Advanced Placement (AP) courses, participated in accelerated education programs, and received national honors. Significant group differences were found for only 3 of the 19 educational experience items displayed in Table 2 (none emerged for

2. The percentages of talent-search participants who secured a math-science degree are substantially above base-rate expectations for the mid-1980s (viz., approximately 4% for math-science degrees among the general population and 17% for college graduates; U.S. Department of Education, 1998).

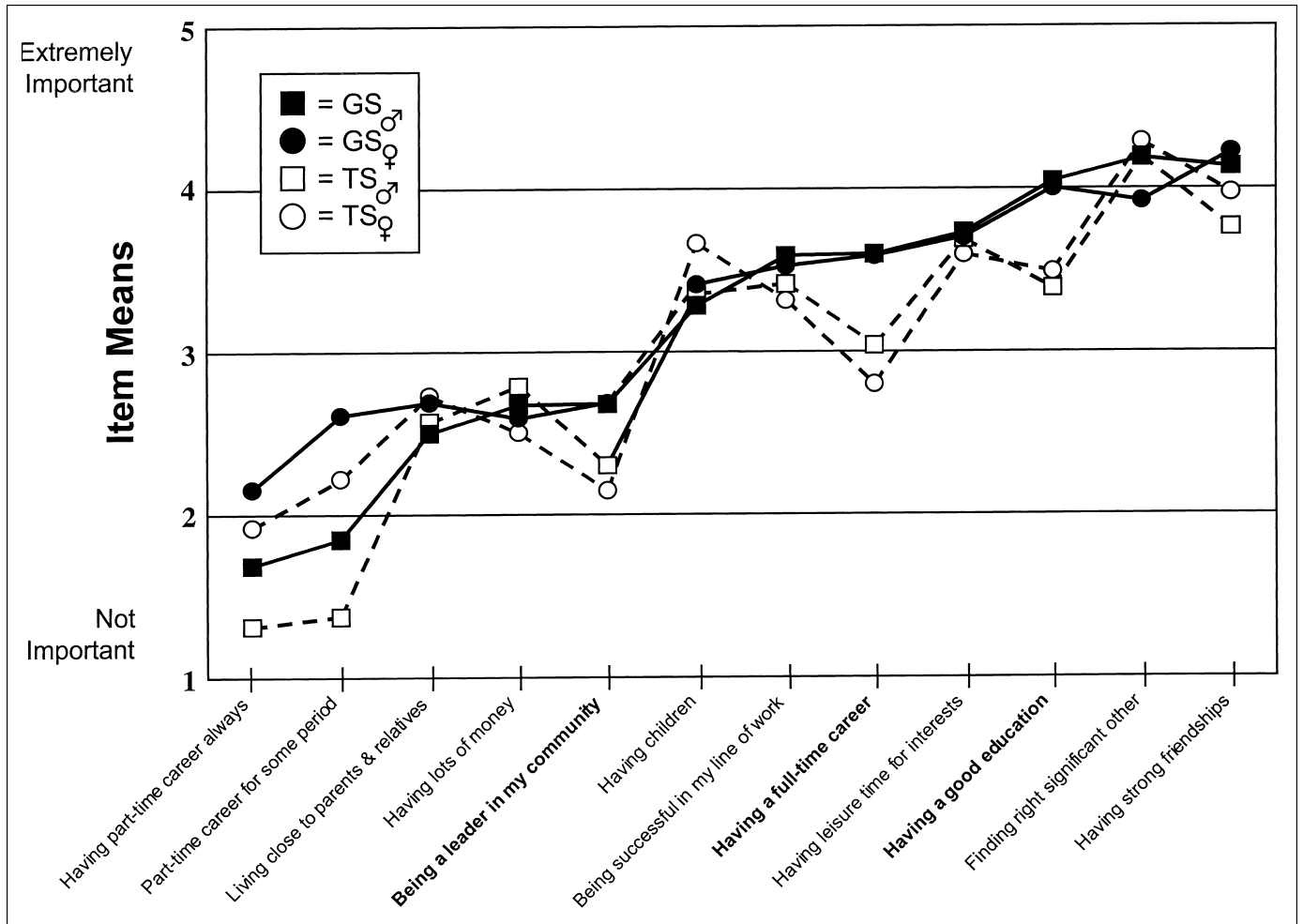


Fig. 2. Importance ratings for items reflecting personal views and lifestyle preferences. Group *ns* varied slightly by item; minimums were 335 for graduate student (GS) males, 317 for GS females, 344 for talent-search (TS) males, and 170 for TS females. TS participants answered these items as part of their 20-year follow-up questionnaire.

comparisons between male and female graduate students): participating in a math-science contest or special program before college, $\chi^2(3, N = 1,251) = 20.6, p < .001$; participating in a math-science contest or special program during college, $\chi^2(3, N = 1,173) = 11.1, p < .05$; and favorite high school class being in math or science, $\chi^2(3, N = 1,223) = 87.7, p < .001$. On the first two items, talent-search females differed significantly from all the other groups, with no other significant differences remaining, minimum $\chi^2(1) = 12.4, p < .001$, and minimum $\chi^2(1) = 6.03, p < .05$, respectively. For the third item, talent-search males and females both differed significantly from graduate student males and females, minimum $\chi^2(1) = 9.4, p < .01$, and minimum $\chi^2(1) = 25.5, p < .001$, for males and females, respectively.

For another benchmark, nearly all of the talent-search participants secured 4-year undergraduate degrees (95% of males, 97% of females), yet 64% of the males and 34% of the females earned 4-year degrees in math-science, $\chi^2(1, N = 592) = 44.0, p < .001$.

Table 3 displays information regarding both formal and informal educational experiences of the graduate students from elementary school onward. Again, close similarity is evident between males and females:

Among the 27 items displayed, no statistically significant sex difference emerged ($\alpha = .05$).³ After reading a description of what qualifies seventh graders for talent-search opportunities, most graduate students who had not participated in such a program felt they would have qualified; less than 9% of each sex felt they would not have. Also, when provided with opportunities for educational acceleration and other educational experiences important for high-level development of abilities and skills, graduate students participated often and tended to rate their experiences positively. The gender similarity in course selection and program participation during high school is remarkable. The information in Tables 2 and 3 reveals that, regardless of sex, the graduate students' secondary

3. Participants also completed the Adjective Check List (Gough & Heilbrun, 1983), but space limitations preclude a comprehensive detailing of these results here. All 36 scales were scored for both sexes, and males and females ranked the same scales 1 and 36. For both sexes, "creative personality" was ranked first, whereas the lowest-ranked scale was "succorance," perhaps reflecting a psychological constellation indicative of independently minded creative innovators.

Table 2. Percentage of participants with various educational experiences

Experience	Graduate students		Talent-search participants	
	Males	Females	Males	Females
Interest in math-science stimulated by a special person	61	69	68	73
Math-science contest or special program before college	58	54	54	37
Accelerated primary or secondary education . . .				
via advanced subject-matter placement	58	62	68	60
via Advanced Placement or other exams for college credit	66	67	92	88
via college courses during high school	33	33	37	29
via grade skipping	11	13	23	28
by any means	88	91	92	92
Reported influence of accelerated experience				
Positive	78	80	70	70
Negative	2	1	10	8
Took biology, chemistry, physics, and calculus during high school	68	66	65	60
Favorite high school class was in math or science	79	74	64	39
Selected for the National Honor Society	70	79	63	70
Was National Merit finalist	23	21	42	38
Awarded National Merit Scholarship	15	17	23	21
Was Presidential Scholar	13	13	3	5
Experienced mentoring relationship before college	28	28	33	34
Positive influence on educational-career plans	96	97	95	89
Negative influence on educational-career plans	3	0	2	2
Math-science contest or special program during college	20	21	25	11

Note. Items with important differences between groups are displayed in boldface. Group *ns* vary by item.

school years involved much intellectual engagement, with challenging curricula and other educational ventures. Development of talent in math and science began early and was maintained at high (and ever-increasing) levels. Regardless of sex, most of the graduate students spent at least 50 hr per week conducting research and studying (independent of going to class) in working toward their graduate degrees.

DISCUSSION

The dispositional and experiential profile of the graduate students, like that of the talent-search participants, clearly reflects the potential to do many things extremely well. Yet this does not imply equal potential for all career paths (Achter, Lubinski, & Benbow, 1996). The pattern of the graduate students' abilities and preferences points to a greater affinity for scientific endeavors relative to the talent-search participants. Indeed, when the data regarding cognitive, affective, and conative attributes are taken together, the profiles for both the male and the female graduate students are consistent with the characteristics identified by earlier studies of exceptional male scientists (Roe, 1953; Terman, 1954; Walberg, 1969; Zuckerman, 1977): pronounced quantitative reasoning ability relative to verbal ability, salient scientific interests and values, a remarkable amount of energy, and, well before college, a clear preference for math-science course work.

A huge literature in vocational psychology shows that people make educational and career choices partly as a function of their abilities and interests, and that this is effective. When individuals are in environments where their abilities, interests, and values match the learning-performance demands and reward structures, they are more likely to work hard at fully developing their talents (Dawis, 1992; Dawis & Lofquist, 1984;

Holland, 1997; Lubinski, 1996, 2000; Tyler, 1974, 1992; Williamson, 1965). We have suggested, therefore, that for optimizing talent development, individuals should find environments congruent with the salient features of their individuality (Lubinski & Benbow, 2000). Both male and female graduate students in the present study are in correspondent environments; that is, their profiles of abilities and preferences match the learning and work requirements and the reward structures of world-class scientific environments.

Another requisite for the emergence of world-class expertise is early skill development and knowledge acquisition. Some researchers have suggested that it takes more than 10 years to develop the knowledge and skills necessary to move a complex discipline forward (Ericsson, 1996; Simonton, 1988). Many accept the "early start" and "long duration" requirements for excellence in athletics and the arts, but are unsure of the importance (or even appropriateness) of these requirements for academic and scientific pursuits. The male and female graduate students in the current study, however, began to self-select opportunities for developing the skills prerequisite for scientific distinction early in their lives (even before secondary school) and in like fashion. This process intensified as they matured, suggesting that aspects of developing truly exceptional scientific expertise mirror the development of extraordinary skills in other domains: Individuals who have personal attributes placing them at promise for eminence (scientific or otherwise) develop that promise only by virtue of expending much effort over protracted time intervals.

Group Differences

In contrast to the male and female graduate students, the male and female talent-search participants showed marked sex differences in their

Table 3. Educational experiences of the graduate students

Experience	Males	Females
Participated in a talent search during junior high school	15	13
Believe would have been eligible for a talent search	63	62
Believe would not have been eligible for a talent search	7	8
Would have enrolled in a talent search	65	72
Gifted programs were available at some point	74	78
Participated in a gifted program (given program was available)	86	84
Average number of years participated in a gifted program (<i>SD</i>)	5.2 (2.9)	5.4 (2.9)
Participated in a summer program for the gifted	26	23
Positive experience from gifted programs	67	71
Negative experience from gifted programs	3	3
Worked on an independent research project during high school	25	23
Took honors course during high school in		
Humanities	52	59
Social studies	42	45
Languages	30	38
Science	66	68
Changed undergraduate major	29	35
Changed from a program outside math-sciences	12	11
Age decided on undergraduate major (<i>SD</i>)	17.7 (2.1)	18.1 (1.8)
Participated in an undergraduate research program	83	83
Positive influence on career-educational plans	88	88
Negative influence on career-educational plans	5	4
Experienced mentoring relationship as undergraduate	57	61
Positive influence on educational-career plans	96	94
Negative influence on educational-career plans	1	3
Member of undergraduate honor society (e.g., Phi Beta Kappa)	71	76
Median number of graduate school hours per week spent on		
Studying	20	20
Research	30	30

Note. No significant differences were found ($\alpha = .01$). Statistics represent percentages, except where specified otherwise.

abilities, interests, and values; hence, they will likely differ in how they derive satisfaction from education and the world of work (Benbow et al., 2000; Kleinfeld, 1998–1999). In general, mathematically talented females display a more balanced SAT profile than similarly talented males, as well as a less focused math-science educational-vocational orientation

(Achter et al., 1996, 1999; Lubinski, Benbow, & Morelock, 2000; Lubinski, Webb, Morelock, & Benbow, in press; Schmidt et al., 1998). In particular, they gravitate more frequently toward opportunities involving “people contact” and “organic” rather than “inorganic” disciplines (as their ability-preference profile would suggest). This might help explain the (relatively quick) closing of the gender gap in law, humanities, medicine, and biological and social sciences in the time since those fields have opened up to women (although men continue to be overrepresented in engineering and the physical sciences). Indeed, women are now overrepresented in many subdisciplines of these fields, which is understandable given that mathematically gifted males and females earn commensurate proportions of advanced educational credentials, but, like undergraduate students, select majors differentially (Benbow et al., 2000).

These findings have implications regarding the representation of females in engineering and the physical sciences (Committee for Economic Development, 1998; National Science and Technology Council, 2000). Contemporary examinations of gender disparities in math and science have focused on environmental climate and differential opportunity (Mervis, 1999b, 2000). Although these are important, the set of determinants of sex differences in educational-vocational outcomes appears more complex. Our findings indicate that differences in choice between males and females are also relevant, but these differences do not necessarily involve how choices are made. For both sexes, choices are partly a function of their ability-preference profile, a fact that vocational psychologists have long discussed (Dawis, 1992; Tyler, 1974, 1992; Williamson, 1965). Moreover, the salient features of these profiles begin to stabilize around age 13 in intellectually precocious populations (Achter et al., 1999; Lubinski et al., 1995, 1996, 2000, in press; Schmidt et al., 1998; Shea, Lubinski, & Benbow, in press) and manifest conspicuous sex differences that anticipate male-female differences in educational-vocational outcomes.

Implications for Talent Development and Educational Policy

What are the implications of this study for assessing the adequacy of education and means of talent development in the United States? What might be the best path for producing world-class scientific talent in sufficient quantity, and how can the country find its way to that path? Not surprisingly, exceptional math-science graduate students constitute a subset of the mathematically gifted population. Like other talented students, they appear to thrive when educational curricula are presented at a developmentally appropriate level and pace (Benbow & Stanley, 1996; Kulik & Kulik, 1992; Stanley, 2000). They take much advanced course work, which speaks to the importance of schools holding high expectations and providing challenging curricula. For curricula to be challenging to all students, however, some individualization is needed, because all students are not at the same place developmentally, and students do not even progress at the same rate. Individualization can be accomplished through acceleration, an approach taken by the graduate students in the current study. But challenging curricula within the classroom are not sufficient to produce world-class achievements; and indeed, the graduate students went well beyond excelling in prescribed curricula. They participated in research, special programs, and many other out-of-school or informal learning opportunities. They took advantage of available opportunities (e.g., 85% participated in gifted programs when available). Many reported participating in research opportunities or being influenced by a mentor before college; given how hard it is to find mentors and re-

search opportunities at this stage of development, this might signify an important catalyst.

We believe our findings support the importance of providing special opportunities and advanced course work for talented youth if they are to develop their potential—and such opportunities also serve many human capital needs in today's world, with its ever-increasing technological and knowledge demands (Levin & Stephen, 1999). Certainly, schools should be emboldened to not only raise the mean but also lift the top to new levels of achievement. Schools and programs that value academic achievement and are responsive to differential learning rates facilitate the emergence of extraordinary achievement, especially for females (Benbow, Lubinski, & Suchy, 1996; Benbow & Stanley, 1996). Moreover, flexibility in age of access to learning opportunities and in time provided for learning is essential (Benbow & Stanley, 1996). Demonstrated competence, not age, should be the means for determining suitability for more advanced opportunities.

Finally, if the United States is to remain true to the ideals that all students be given access to opportunities for developing their potential and that people be allowed to choose their life paths freely, this might require questioning whether males and females should be equally represented across the full educational-vocational spectrum. Although there is no reason to anticipate sex differences in the proportion of advanced educational credentials achieved by intellectually precocious youth (Benbow et al., 2000; Lubinski et al., in press), our data suggest that there may be a need to consider a degree of unequal representation in both directions across various disciplines (Benbow, 1992; Lubinski et al., 2000). Is it acceptable, for example, to have greater numbers of women than men in high-power careers in medicine and law but the inverse in engineering and the physical sciences? The data reported here and elsewhere (Halpern, 2000; Hedges & Nowell, 1995; Humphreys et al., 1993; Kimura, 1999; Lubinski & Humphreys, 1990) suggest that such gender-differentiating outcomes are likely to ensue if intellectually talented adolescents and young adults are allowed to choose freely how they would like to develop. This is something that the great counseling psychologist Leona E. Tyler (1974) anticipated and reflected on years ago:

In our haste to abolish the unjust and the obsolete, we cannot afford to ignore the psychological realities that generated such systems in the first place. There are highly significant psychological differences among individuals, and the soundness of our social institutions depends upon how successfully we take them into account A complex society cannot regard its members as identical interchangeable parts of a social machine. Its complex functioning depends upon the contributions of individuals specializing along different lines, equipped for carrying out different specialized tasks.

For this reason we must not be content with any system of universal education that provides identical treatment for all pupils. We must look for ways of diversifying education to make it fit the diverse individuals whose talents should be developed and utilized. (pp. 6–7)

In conclusion, developing world-class scientific talent involves more than ability. Ability, especially mathematical reasoning ability, is necessary (Benbow, 1992; Benbow et al., 2000), but it is not sufficient. Achieving scientific eminence also requires the right mix of personal attributes, much effort, and challenging educational opportunities in and out of school. For students with the right mix of these attributes, exposure to research opportunities might be especially influential. The path to world-class scientific distinction, which appears to be similar for males and females, is paved with challenging educational opportunities. When students embrace such opportunities and succeed, early

signs of scientific distinction are revealed. When schools respond to such behaviors by providing opportunities for further development (at the time when students are ready for them), they encourage development of the kinds of skills and work habits needed to achieve and maintain a distinguished scientific career.

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REFERENCES

- Achter, J.A., Lubinski, D., & Benbow, C.P. (1996). Multipotentiality among the intellectually gifted: "It was never there and already it's vanishing." *Journal of Counseling Psychology, 43*, 65–76.
- Achter, J.A., Lubinski, D., Benbow, C.P., & Eftekhari-Sanjani, H. (1999). Assessing vocational preferences among intellectually gifted adolescents adds incremental validity to abilities: A discriminant analysis of educational outcomes over a 10-year interval. *Journal of Educational Psychology, 91*, 777–786.
- Allport, G.W., Vernon, P.E., & Lindzey, G. (1970). *Manual: Study of Values*. Boston: Houghton Mifflin.
- Assouline, S.G., & Lupkowski-Shoplik, A.E. (1997). Talent searches: A model for the discovery and development of academic talent. In N. Colangelo & G.A. Davis (Eds.), *Handbook of gifted education* (2nd ed., pp. 170–179). Boston: Allen & Bacon.
- Ayers, T. (1999). Congressional hearings link science education to jobs. *Science, 284*, 830.
- Benbow, C.P. (1988). Sex differences in mathematical reasoning ability among the intellectually talented. *Behavioral and Brain Sciences, 11*, 169–232.
- Benbow, C.P. (1992). Academic achievement in mathematics and science of students between ages 13 and 23: Are there differences among students in the top one percent of mathematical ability? *Journal of Educational Psychology, 84*, 51–61.
- Benbow, C.P., Lubinski, D., Shea, D.L., & Eftekhari-Sanjani, H. (2000). Sex differences in mathematical reasoning ability: Their status 20 years later. *Psychological Science, 11*, 474–480.
- Benbow, C.P., Lubinski, D., & Suchy, B. (1996). The impact of SMPY's educational programs from the perspective of the participant. In C.P. Benbow & D. Lubinski (Eds.), *Intellectual talent: Psychometric and social issues* (pp. 166–300). Baltimore: Johns Hopkins University Press.
- Benbow, C.P., & Stanley, J.C. (1996). Inequity in equity: How "equity" can lead to inequity for high potential students. *Psychology, Public Policy, and Law, 2*, 249–292.
- Cohn, S.J. (1991). Talent searches. In N. Colangelo & G.A. Davis (Eds.), *Handbook of gifted education* (pp. 166–177). Boston: Allen and Bacon.
- College Entrance Examination Board. (1992). *College bound seniors: 1992 profile of SAT and achievement test takers*. Princeton, NJ: Author.
- Colwell, R.R., & Kelly, E.M. (1999). Science learning, science opportunity. *Science, 286*, 237.
- Committee for Economic Development. (1998). *America's basic research: Prosperity through discovery*. New York: Author.
- Dawis, R.V. (1991). Vocational interests, values, and preferences. In M.D. Dunnette & L.M. Hough (Eds.), *Handbook of industrial and organizational psychology* (Vol. 2, pp. 833–871). Palo Alto, CA: Consulting Psychologists Press.
- Dawis, R.V. (1992). The individual differences tradition in counseling psychology. *Journal of Counseling Psychology, 39*, 7–19.
- Dawis, R.V., & Lofquist, L.H. (1984). *A psychological theory of work adjustment*. Minneapolis: University of Minnesota Press.
- Day, S.X., & Rounds, J. (1998). The universality of vocational interest structure among racial/ethnic minorities. *American Psychologist, 53*, 728–736.
- Ericsson, K.A. (1996). *The road to excellence*. Mahwah, NJ: Erlbaum.
- Eysenck, H.J. (1995). *Genius*. Cambridge, England: Cambridge University Press.
- Gough, H.G., & Heilbrun, A.B. (1983). *The Adjective Checklist manual*. Palo Alto, CA: Consulting Psychologists Press.
- Gourman, J. (1989). *The Gourman report: A rating of graduate and professional programs in American and international universities*. Los Angeles: National Educational Standards.
- Halpern, D.F. (2000). *Sex differences in cognitive abilities* (3rd ed.). Hillsdale, NJ: Erlbaum.
- Hansen, J.C., & Campbell, D.P. (1985). *Manual for the SCII* (4th ed.). Palo Alto, CA: Stanford University Press.
- Harmon, L.W., Hansen, J.C., Borgen, F.H., & Hammer, A.L. (1994). *Applications and technical guide for the Strong Interest Inventory*. Palo Alto, CA: Consulting Psychologists Press.
- Hedges, L.V., & Nowell, A. (1995). Sex differences in mental test scores, variability, and numbers of high scoring individuals. *Science, 269*, 41–45.
- Holden, C. (2000). Parity as a goal sparks bitter battle. *Science, 289*, 380.

- Holland, J.L. (1997). *Making vocational choices* (3rd ed.). Odessa, FL: Psychological Assessment Resources.
- Humphreys, L.G., Lubinski, D., & Yao, G. (1993). Utility of predicting group membership and the role of spatial visualization in becoming an engineer, physical scientist, or artist. *Journal of Applied Psychology, 78*, 250–261.
- Jackson, D.N., & Rushton, J.P. (1985). *Scientific excellence*. Newbury Park, CA: Sage.
- Kimura, D. (1999). *Sex and cognition*. Cambridge, MA: MIT Press.
- Kleinfeld, J. (1998–1999, Winter). The Morella Bill, my daughter Rachel, and the advancement of women in science. *Academic Quarterly, 12*, 79–86.
- Kulik, J.A., & Kulik, C.C. (1992). Meta-analytic findings on grouping programs. *Gifted Child Quarterly, 36*, 73–77.
- Lehrman, S. (1999). AAAS head wants to see scientists on school boards. *Nature, 397*, 374.
- Levin, S.G., & Stephan, P.E. (1999). Are foreign born a source of strength for U. S. science? *Science, 285*, 1213–1214.
- Lofquist, L.H., & Dawis, R.V. (1991). *Essentials of person environment correspondence counseling*. Minneapolis: University of Minnesota Press.
- Lubinski, D. (1996). Applied individual differences research and its quantitative methods. *Psychology, Public Policy, and Law, 2*, 187–203.
- Lubinski, D. (2000). Scientific and social significance of assessing individual differences: "Sinking shafts at a few critical points." *Annual Review of Psychology, 51*, 405–444.
- Lubinski, D., & Benbow, C.P. (1994). The Study of Mathematically Precocious Youth: The first three decades of a planned 50-year study of intellectual talent. In R.F. Subotnik & K.D. Arnold (Eds.), *Beyond Terman: Contemporary longitudinal studies of giftedness and talent* (pp. 255–281). Norwood, NJ: Ablex.
- Lubinski, D., & Benbow, C.P. (2000). States of excellence. *American Psychologist, 55*, 137–150.
- Lubinski, D., Benbow, C.P., & Morelock, M.J. (2000). Gender differences in engineering and the physical sciences among the gifted: An inorganic-organic distinction. In K.A. Heller, F.J. Monks, R.J. Sternberg, & R.F. Subotnik (Eds.), *International handbook for research on giftedness and talent* (2nd ed., pp. 627–641). Oxford, England: Pergamon Press.
- Lubinski, D., Benbow, C.P., & Ryan, J. (1995). Stability of vocational interests among the intellectually gifted from adolescence to adulthood: A 15-year longitudinal follow-up. *Journal of Applied Psychology, 80*, 196–200.
- Lubinski, D., & Humphreys, L.G. (1990). A broadly based analysis of mathematical giftedness. *Intelligence, 14*, 327–355.
- Lubinski, D., Schmidt, D.B., & Benbow, C.P. (1996). A 20-year stability analysis of the Study of Values for intellectually gifted individuals from adolescence to adulthood. *Journal of Applied Psychology, 81*, 443–451.
- Lubinski, D., Webb, R.M., Morelock, M.J., & Benbow, C.P. (in press). Top 1 in 10,000: A 10-year follow-up of the profoundly gifted. *Journal of Applied Psychology*.
- Mervis, J. (1999a). Efforts to boost diversity face persistent problems. *Science, 284*, 1757.
- Mervis, J. (1999b). High level groups study barriers women face. *Science, 284*, 727.
- Mervis, J. (2000). NSF searches for right way to help women. *Science, 289*, 379, 381.
- National Research Council. (1987). *Summary report 1986: Doctoral recipients from United States universities*. Washington, DC: National Academy Press.
- National Science and Technology Council. (2000, April). *Ensuring a strong U.S. scientific, technical, and engineering workforce in the 21st century* [On-line]. Available: <http://www.whitehouse.gov/WH/EOP/OSTP/html/workforcerpt.pdf>
- National Science Foundation. (1999). *Program for women and girls* [On-line]. Available: <http://www.nsf.gov/verity/srchawd.html> [type 1544 in dialogue window]
- Roe, A. (1953). *The making of a scientist*. New York: Dodd, Mead.
- Schmidt, D.B., Lubinski, D., & Benbow, C.P. (1998). Validity of assessing educational-vocational preference dimensions among intellectually talented 13-year olds. *Journal of Counseling Psychology, 45*, 436–453.
- Shea, D.L., Lubinski, D., & Benbow, C.P. (in press). Importance of assessing spatial ability in intellectually talented young adolescents: A 20-year longitudinal study. *Journal of Educational Psychology*.
- Simonton, D.K. (1988). *Scientific genius*. Cambridge, England: Cambridge University Press.
- Stanley, J.C. (2000). Helping students learn what they don't already know. *Psychology, Public Policy, and Law, 6*, 216–222.
- Terman, L.M. (1954). Scientists and nonscientists in a group of 800 gifted men. *Psychological Monographs: General and Applied, 68*, 1–45.
- Tyler, L.E. (1974). *Individual differences: Abilities and motivational directions*. Englewood Cliffs, NJ: Prentice-Hall.
- Tyler, L.E. (1992). Counseling psychology—Why? *Professional Psychology: Research and Practice, 23*, 342–344.
- U.S. Department of Education. (1998). *Digest of educational statistics* (NCES Publication No. 1999–036). Washington, DC: U.S. Government Printing Office.
- Walberg, H.J. (1969). A portrait of the artist and scientist as young men. *Exceptional Children, 35*, 5–12.
- Wickware, P. (1997). Along the leaky pipeline. *Nature, 390*, 202–203.
- Williamson, E.G. (1965). *Vocational counseling: Some historical, philosophical, and theoretical perspectives*. New York: McGraw-Hill.
- Zuckerman, H. (1977). *Scientific elite*. New York: Free Press.

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