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The Study of Mathematically Precocious Youth: The First Three Decades of a Planned 50-Year Study of Intellectual Talent*

David Lubinski
Camilla Persson Benbow

Our increasingly technological society requires many well-trained scientists. Yet decreasing numbers of college students are choosing engineering, mathematics, and physical science majors (National Science Board, 1982; Office of Technology Assessment, 1988; Turner & Bowen, 1990). For example, between 1966 and 1988, the number of college freshmen majoring in mathematics and science decreased by 50% (Green, 1989). This trend has generated concern among several leaders in the physical sciences, a concern that is amplified by the marked underrepresentation of women in engineering and physical sciences, especially at advanced educational levels and among faculty in math/science departments. Many educational and vocational psychologists have embraced these concerns. Some have been moved to ask: Within our student population, are there measurable psychological attributes that are predictive of individuals who will maintain a commitment to and achieve career excellence in math/science disciplines (and are these attributes gender-differentiating)? Whatever psychologists do to address the mounting concern over our future technological capabilities, addressing both components of the aforementioned question (i.e., maintaining a commitment and achieving excellence) is critical. After all, simply enhancing the number of individuals who ulti-

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*Address correspondence to either Camilla P. Benbow or David Lubinski, Co-Directors of the Study of Mathematically Precocious Youth (SMPY), Department of Psychology, Iowa State University, Ames, IA 50011-3180. Support was provided by a grant from the National Science Foundation (MDR 8855625).

mately earn advanced degrees in engineering or the physical sciences would be counterproductive if these individuals ultimately found themselves either occupationally unfulfilled or unable to work competently in engineering and physical science careers.

In this chapter, we will describe the planned 50-year longitudinal study that is being conducted by the Study of Mathematically Precocious Youth (SMPY), a study that is now in its third decade. To enrich this description, we will illustrate how this data bank can be used to address the aforementioned student problem that currently has attracted much attention among educators within the math/science pipeline and educational and vocational psychologists outside of it. Specifically, we will present data from SMPY and the psychological literature that have relevance for identifying the early psychological antecedents of competence and satisfaction at all points along the math/science pipeline, from selecting a college major to earning a doctorate in a technical discipline. Factors especially conducive to exceptional achievements will be given particular attention, as will special influences that contribute to the optimal educational and vocational development of the nascent physical scientist; possible influences related to gender differences in achievement will be stressed throughout. The chapter begins, therefore, with a description of SMPY itself, which is followed by a brief outline of the theoretical model guiding our research and employed to organize the study's empirical findings.

THE STUDY OF MATHEMATICALLY PRECOCIOUS YOUTH (SMPY)

SMPY was founded by Julian C. Stanley in September 1971 at Johns Hopkins University. The practical premise guiding the work of SMPY is and has been to conduct research through service to intellectually gifted adolescents with a special emphasis on the mathematically talented. By providing innovative educational programs and educational guidance, SMPY's aim is to facilitate individual development toward academic achievement from the early identification of exceptional intellectual talent (Stanley, 1977; Stanley & Benbow, 1986). In the process, SMPY attempts to discover the optimal mechanisms that promote both intellectual and social well-being among the gifted. To facilitate meeting these goals, SMPY established a 50-year longitudinal study, which currently includes about 5,000 mathematically and/or verbally talented individuals identified over a 20-year period. Through this study, SMPY is trying to develop a better understanding of the processes whereby precocious forms of intellectual talent, identified during childhood, develop into noteworthy products of adult achievement and creativity.

The Conception of Mathematical and Verbal Precocity Embedded in SMPY's Selection Procedures

SMPY's conception of mathematical and verbal precocity is the manifestation of exceptional mathematical/verbal reasoning abilities at a very early age. Subjects are selected for our longitudinal study around ages 12 to 13, in the seventh or eighth grade. These students must have earned scores in the top 3% on conventional standardized tests administered in their schools (e.g., Iowa Tests of Basic Skills). This intellectually select group of students is then given the opportunity to take the College Board Scholastic Aptitude Test (SAT) through a "talent search" (a concept developed by SMPY to identify exceptionally able students, cf. Keating & Stanley, 1972).[1] The SAT was designed for above-average high school juniors and seniors to assess mathematical and verbal reasoning abilities critical for university course work (Donlon, 1984). Because talent search participants are four to five years younger than the population of college-going high school seniors for whom the SAT was designed, and because few adolescents have received formal training in algebra or beyond (Benbow, 1992a; Benbow & Stanley, 1982a, 1982b, 1983a), this form of assessment is known as out-of-level testing.

SAT score distributions of 12- to 13 year-olds in the top 3% for their grade level are consistently indistinguishable from those typically observed among high school students (Benbow, 1988). These scores are especially spectacular for the mathematics component of the SAT, inasmuch as without formal training, many of these students score above the cutoff for the most elite universities. Moreover, given the abstract nature of the SAT and the sheer novelty of the problems, it suggests that this instrument functions for these students at a far more analytical reasoning level than it does for high school students who have been exposed explicitly to the specific content of the SAT through high school course work (Benbow, 1983, 1992b; Benbow & Stanley, 1980, 1981, 1983b; Stanley & Benbow, 1986).

For these youngsters, such intellectually abstract problems as those found on the SAT are ideal for revealing systematic sources of intellectual differences among the gifted that are obscured by ceiling effects in conventional instruments. Even among educational researchers, the realization that one-third of the IQ range is found in the top 1% is frequently underappreciated. Assuming an IQ standard deviation of 16, the cut-off score for the top 1% is somewhere

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[1] Talent search programs have recently expanded, allowing gifted students the opportunity to take the ACT.

around 137, but IQs extend beyond 200. In addition, the individual differences found in that range are psychologically meaningful and important to differentiate. The differences in educational accomplishments and career achievements among individuals in the top and bottom quartiles of the top 1% are truly remarkable (Benbow, 1992b). It is clearly useful to differentiate the able from the highly able in upper ability ranges, as well as to structure educational opportunities and acceleration accordingly (Lubinski, Benbow, & Sanders, in press). (For detailed discussions of the SAT's predictive validity within this upper third of the IQ distribution [following 10-year temporal gaps, age 13 to 23] see Benbow [1992b] and Lubinski & Dawis [1992].)

Longitudinal Design of SMPY

A time-line for the longitudinal study is shown in Figure 10.1. There are five cohorts in all: Four were assembled through talent searches, while a fifth cohort is composed of graduate students in top U.S. mathematics and physical science departments. (Each cohort is separated by a few years.) Combined, the cohorts span 20 years, with findings from each cohort serving in part as a replication for similar analyses conducted in other time frames.

Cohort	N	When Identified	Age at Identified	SAT Criteria	Ability Level
1	2188	1972 -1974	12 -13	Verb. ≧ 370 or Math ≧ 390	1%
2	778	1976 -1979	12	Top 1/3 of Talent Search Participants	0.5%
3	423	1980 - 1983		Math ≧ 700 Verb. ≧ 630	0.01%
Comparison Group		1983	12	SAT-M + SAT-V ≧ 540	5%
		1982	12	500 - 590 Math 600 - 690 Verb.	0.5%
4	≧ 1000	1987 -	12	Math ≧ 500 or Verb. ≧ 430	0.5%

Projected time-line for the Study of Mathematically Precocious Youth's (SMPY'S) planned 50-year longitudinal study.

Figure 10.1. The SMPY Longitudinal Study: Its Cohorts of Subjects

Because the students in the first four cohorts were identified over a 20-year period using the same criteria, the study allows for a reasonable assessment of historical effects. Lack of ability to know and measure the extent to which specific historical periods influenced participants' development is a problem associated with most longitudinal studies. For example, we do not know how being a young adult during the Great Depression affected the development and achievement of participants in the *Genetic Studies of Genius* (Terman, 1925-1957). Similar data collected across multiple time points allow some degree of control of such historical influences in the SMPY study. SMPY will be able to ask, for example, what difference it makes, in terms of ultimate achievement, to have been a gifted adolescent in the early 1970s versus the 1990s.

Another unique aspect of the SMPY design is the ability to modify and add new assessment materials. Cohort 4 grows by approximately 400 participants each year, allowing us to ask questions not pertinent to 1972 participants. For example, we are currently assessing the relationship between family climate and giftedness, using the Moos and Moos Family Environment Scale (Moos & Moos, 1986), which was not available in 1972. The currency of the study is, therefore, maintained. A retrospective/longitudinal study of graduate students in the nation's top engineering, mathematics, and physical science departments has been initiated (Cohort 5) to ascertain whether such students differ in substantive ways from students identified via the talent search.

Cohorts

The first four SMPY cohorts were formed using different ability cutoffs on the SAT. The first three cohorts are successively more able, while the fourth, consisting of primarily Midwestern residents who are being identified through the Office of Precollegiate Programs for Talented and Gifted (OPPTAG) at Iowa State University, represents the same ability level as Cohort 2. A detailing of each cohort outlined in Figure 10.1 is given below.

Cohort 1 was identified in SMPY's March 1972, January 1973, and January 1974 Talent Searches as seventh or eighth graders scoring at least 390 on the SAT-M or 370 on the SAT-V. Those cutoff scores were selected because they represented the average performance of a random sample of high school females on the SAT. Students were drawn primarily from the state of Maryland, with a heavy concentration from the greater Baltimore area. Cohort 2 is comprised of at least the top third of seventh-grade students from SMPY's December 1976, January 1978, and January 1979 Talent

Searches (using cutoff scores at or above the top .5% in ability nationally). These students were drawn from the Mid-Atlantic states. It should be noted that these first two cohorts are separated by at least three years. About 60% of the participants are male.

Cohort 3 is comprised of three groups and is national in its representation. It consists of approximately 300 students who scored at least 700 on SAT-M before age 13 between November 1980 and November 1983.[2] It also includes more than 150 students scoring at or above 630 on SAT-V before age 13. (These scores represent the top 1 in 10,000 for mathematical and verbal reasoning abilities, respectively.) Finally, for comparison purposes, Cohort 3 includes 100 seventh-grade students scoring at chance on SAT (i.e., SAT-M + SAT-V 540) in the 1983 Talent Search conducted by the Center for Talented Youth (CTY) at Johns Hopkins University. Because chance performance tends to imply low ability, it is important to keep in mind that this last group's ability level is still in the top 3-5% on national norms (only students in the top 3-5% in ability can enter a Talent Search); thus, by most definitions they too would be considered modestly gifted.

Cohort 4 consists of 1,000 students, primarily Midwesterners, scoring before age 13 at least 500 on SAT-M, 430 on SAT-V, *or* at least 20 on an ACT subtest/composite. Like Cohort 2, they represent the top .5% in ability. Students in Cohort 4 had enrolled in Iowa State's summer program for intellectually talented youth. At present, several comparison groups also are being formed from the Iowa Talent Search, which screens students with abilities in the top 3% in the nation, as well as from students in the normative ability range.

Finally, Cohort 5 contains over 750 individuals from various engineering, mathematics, and physical science disciplines who are currently enrolled in the United States' top graduate programs. Approximately 50% of the sample consists of females. In 1991, we secured permission from the Chairs of 48 of a subset of this country's best engineering, mathematics, and physical science graduate training programs to survey their graduate students on a number of the key variables used in our research on Talent Search participants. This sample was surveyed in the spring of 1992, with a response rate of 93%.

Collectively, the five cohorts of SMPY comprise approximately 5,000 highly able students. This number will soon increase to about 6,000. All of the students in the five cohorts are being surveyed at critical junctures throughout their youth and adult lives, as can be

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[2]Some of the examples provided may not involve actual Cohort 3 members, but individuals identified by Julian Stanley using the same criteria.

seen in the timeline in Figure 10.1. Each cohort, moreover, will be surveyed at the same ages to ensure comparability of findings across cohorts.

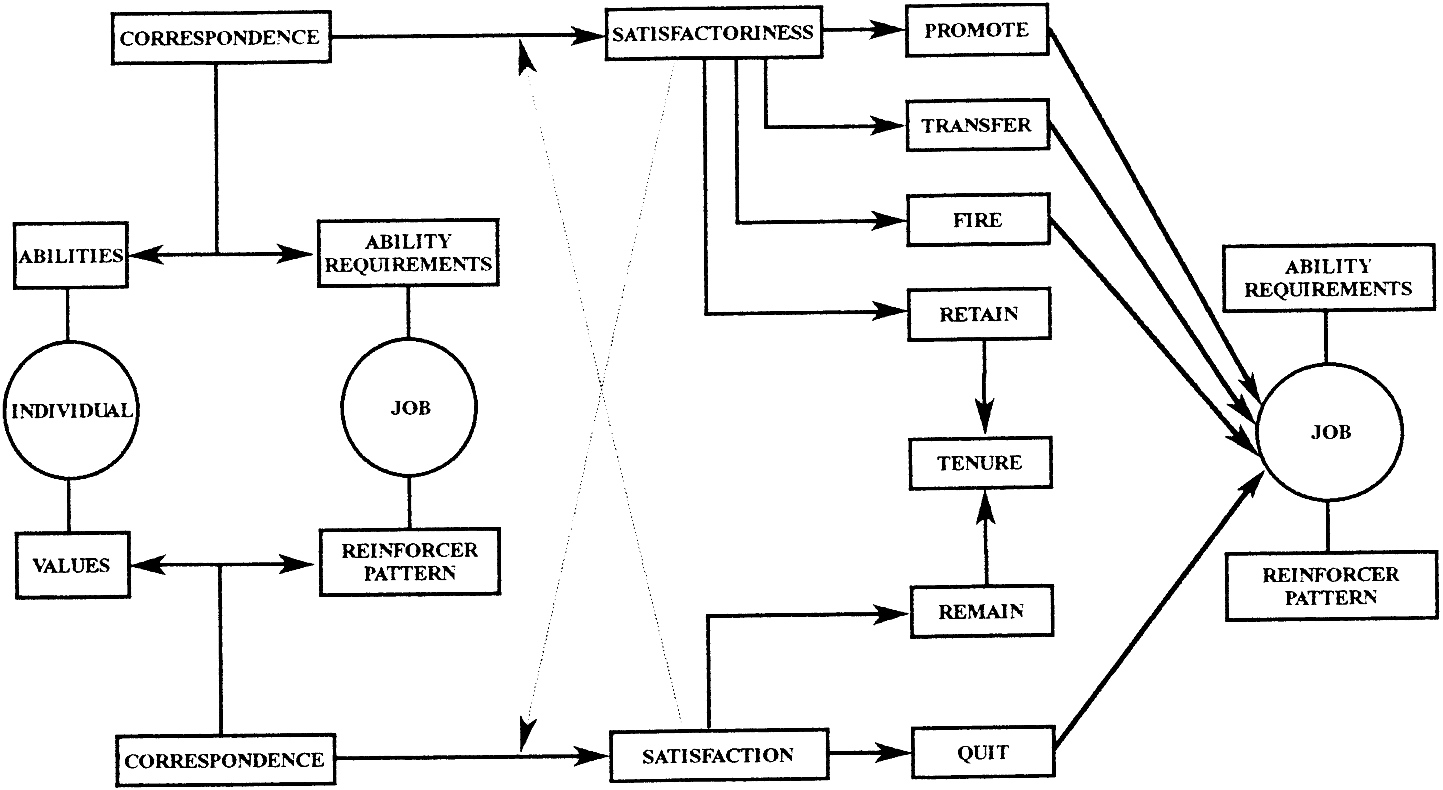
Status of Longitudinal Study

To date, we have surveyed Cohort 1 at age 13, 18, 23, and 33 (in progress). Cohort 2 also has been surveyed at ages 13, 18, and 23, with the last survey just being completed. Cohort 3 has been surveyed at ages 13, 18, and 23 (in progress). Cohort 4 has been surveyed at age 13 and 18 (in progress). Cohort 5 has been surveyed at age 23 only, but that survey included much retrospective information. Response rates to our several follow-up surveys range from 75% to well over 90%. Respondents do not differ from nonrespondents on key variables including ability, family background, and college attendance (Benbow & Arjmand, 1990; Benbow & Stanley, 1982a). We now turn to a presentation of the theoretical model that guides our work.

THEORETICAL MODEL

What information is most profitable to collect from the SMPY participants and how is this information best organized? Data we collect correspond to the central components of the Theory of Work Adjustment (TWA). TWA was initially developed to conceptualize the critical determinants of adjustment to work (Dawis & Lofquist, 1984; Lofquist & Dawis, 1969, 1991). The predictive utility of TWA is revealed in its capacity to forecast the length of time an individual is likely to stay in a given occupation or career track. This model is appropriate for SMPY because it addresses the determinants of vocational pathways, such as being more attracted to academic versus vocational/technical coursework in high school or choosing a college major. It also is useful for better understanding the amount of coursework students are likely to desire in various disciplines as a function of their abilities and preferences. A schematic representation of TWA is found in Figure 10.2.

According to TWA, two critical dimensions of correspondence operate in concert to structure educational and career development, *satisfaction* and *satisfactoriness*. Satisfaction is a subjective parameter estimated by the student or employee; it has to do with how the person feels in a particular learning or occupational environment (determined by the extent to which an individual's needs correspond to the educational/occupational reinforcers or reward structures); satisfactoriness is an objective parameter estimated by data collected by educators and employers (determined by the extent to which an



A depiction of the theory of work adjustment. (Adapted from Dawis and Lofquist, 1984.) The dotted lines serve to illustrate how satisfaction and satisfactoriness function jointly to determine educational/career tenure. When an individual is not satisfactory the environment is motivated to transfer or fire the individual, whereas if the individual is not satisfied, the person is motivated to leave.

Figure 2

individual's abilities correspond to the educational/occupational requirements). Satisfaction is predictive of how motivated an individual is likely to be in pursuing a particular educational/vocational path, whereas satisfactoriness predicts how highly an educational program or career track will value an individual.

Put another way, individuals are motivated to meet their needs or to attain reinforcers. To secure these commodities, they will exercise their abilities. Work environments also have needs, needs for individuals with certain abilities. To attract these people, work environments offer certain reinforcers. Therefore, in ideal settings, a mutual correspondence is established and defines a special kind of ("ideal") person/environment interaction, which, in occupational environments, is called *vocational adjustment*. This theory places equal emphasis on assessing the individual and the environment. Educational and work environments are assessed for their ability requirements and reward structure, while individuals are assessed for their ability levels and specific needs or preferences.

Intellectual Abilities

There are many different kinds of human abilities (cognitive, perceptual, psychomotor) predictive of educational and vocational excellence and success. But, clearly, intellectual abilities are most central to securing advanced educational credentials and achieving excellence in the sciences. The psychological literature reveals considerable consensus about how intellectual abilities are organized (Ackerman, 1987, 1988; Carroll, 1985; Humphreys, 1979; Lubinski & Dawis, 1992; Snow et al., 1984). There are basically three broad categories of human intellectual abilities predictive of educational and vocational performance criteria. All three categories are defined by distinct representational or symbolic systems: verbal/linguistic, numerical/quantitative, and spatial/mechanical. All three classes share appreciable communality, what is typically referred to as general intelligence or the general factor (*g*) cutting across all types of cognitive tests. Individual differences in one's facility with these three representational/symbolic systems hold different implications for channeling development and forecasting competence in contrasting educational/vocational paths (Gottfredson, 1986, 1988; Humphreys, Lubinski, & Yao, 1993; Lubinski & Dawis, 1992). Assessing individual differences in these three content domains of talent (plus the general factor defined by their communality) provides ideal information for educational, personnel, and vocational psychologists.

With respect to the substantive focus of this chapter, where engineering and the physical sciences are at center stage, being facile at mathematical reasoning is at premium. But evidence is mounting to suggest that spatial abilities are of secondary importance and perhaps of even greater importance than verbal abilities (Humphreys et al., 1993). This is certainly the case for most engineering occupations. Nevertheless, all three systems of content are important in any mathematics or science career. We highlight spatial abilities because although academic and applied psychologists have keenly appreciated the importance of both verbal and quantitative abilities for achieving advanced educational credentials, many have tended to underestimate the critical importance of spatial abilities for math/science disciplines. Tests of mechanical reasoning and spatial visualization are typically restricted to use in regard to nonprofessional technical careers. Yet many graduate degrees in the technical disciplines require appreciable levels of spatial visualization (Humphreys et al., 1993). Because we have relatively comprehensive assessments of our Talent Search participants' quantitative and verbal abilities (they take the SAT to qualify for our educational programs for the gifted), we administer a number of spatial and mechanical reasoning tests to assess their status on these abilities as well. All three classes of abilities are assessed by SMPY in its work with intellectually talented students.

Preferences (Interests and Values)

For years, psychologists have known that vocational interests and values are among the most critical determinants of contrasting educational paths and vocational choices (Benbow & Lubinski, in press; Dawis, 1991). Two of the most well-known systems and measures for assessing these attributes are Holland's Hexagon (Holland, 1985) and the Allport, Vernon, and Lindzey (1970) Study of Values (SOV). Interestingly, both instruments consist of six major preference dimensions or evaluative attitudes; in addition, they share appreciable overlap. Holland's Hexagon consists of the following General Interest Themes (with prototypic careers of individuals with high standing given in parentheses): Realistic (Agriculture, Mechanical/Technical), Investigative (Physicist, Professor), Artistic (Writer, Artist), Social (Counselor, Social Worker, Teacher), Enterprising (Executive, Marketing/Sales), and Conventional (Office Support Staff). The dimensions of the SOV correspond to and correlate highly with Holland's Themes: Political, Theoretical, Aesthetic, Social, Economic, and Religious, respectively.

Using these two systems, physical scientists tend to be distinguished by their high investigative qualities followed secondarily by high realistic scores, plus relatively low normative standing on the social dimension. Similarly, on the SOV, engineers and physical scientists have markedly high theoretical values (preference for working with ideas) and relatively low social values (preference for working with people). This pattern corresponds to a "people versus things" dimension dating at least back to Thorndike (1911), one of the most prominent preference dimensions found in the psychology of individual differences. This dimension also manifests marked gender differences, both in normative samples and among the gifted, as will be discussed below.

THE DATA

Contemporary data collected at Iowa State University (ISU) over the last five years (1988-1992) in our programs for the gifted exemplify how we assess abilities beyond those tapped by the SAT as well as critical preferences relevant to educational/vocational development. During the summer, we now profile approximately 400 mathematically and verbally talented youth on a variety of specific abilities and major preference dimensions. Since we are concerned here with engineering and physical science talent, Tables 10.1 and 10.2 contain data from participants at or above the top 2% in mathematical talent (SAT-M 350 at age 13). Students who qualified for our summer programs primarily via their verbal abilities (i.e., their SAT-M was under 350) were omitted. This, in turn, gives a better picture of the gender differences in specific abilities and preferences for individuals who are indeed in possession of at least a minimal amount of quantitative talent for achieving educational and vocational excellence in the physical sciences. Such gender differences, although not central to the study originally, have captured much of SMPY's attention due to their implications and robustness, and are of particular concern in this chapter.

The ability profiles in Table 10.1 reveal that whether the participants are male or female, their specific abilities tend to be highly developed. Moreover, for those meeting the 350 SAT-M cutoff score (or the top 2% in mathematical reasoning ability for 13-year-olds), gender differences in verbal ability (SAT-V) and Advanced Raven's are essentially nonexistent. On a number of key specific abilities, however, including mathematical reasoning ability, pronounced gender differences emerge even at this superior level. For the mathematical reasoning abilities assessed by the SAT, consistent effect sizes favoring males are approximately .50. On tests of three-dimensional spatial visualization and mechanical reasoning, gender differences are even more pronounced (with effect sizes of approximately .80). Clearly, among the mathematically gifted, marked gender differences exist on the two major classes of specific abilities

Table 10.1. Ability Profiles of Mathematically Gifted Students Attending a Summer Academic Program Across Five Separate Years by Gender

YEAR		GENDER	AGE-ADJUSTED					ADVANCED RAVEN'S			MENTAL ROTATION TEST			BENNETT MECHANICAL REASONING		
				SAT-M		SAT-V										
			N	$\bar{X}$	SD	$\bar{X}$	SD	N	$\bar{X}$	SD	N	$\bar{X}$	SD	N	$\bar{X}$	SD
1992	★	M	72	494	93	398	91	72	24.6	4.1	72	31.3	7.7	72	49.8	7.1
		F	45	458	66	396	82	45	24.3	4.4	45	23.7	8.8	45	45.3	5.2
	■	M	84	486	91	395	88	85	24.4	4.2	83	31.6	7.5	83	49.9	7.0
		F	49	465	76	404	90	47	24.6	4.5	48	24.1	8.9	49	45.6	5.2
1991	★	M	68	532	101	426	78	68	25.1	3.9	68	29.9	8.1			
		F	51	480	87	418	87	51	25.8	4.3	51	25.1	10.2			
	■	M	107	579	101	413	81	92	25.2	4.2	95	30.0	8.1			
		F	67	472	85	418	80	58	25.9	4.2	63	24.1	10.0			
1990	★	M	69	537	100	415	79	69	24.5	6.5	69	29.2	9.1			
		F	48	487	74	422	76	48	25.3	4.4	48	22.5	9.7			
	■	M	87	545	96	415	79	82	24.6	6.8	80	29.8	8.8			
		F	61	487	71	419	80	57	25.1	4.1	56	21.6	9.4			
1989	★	M	20	585	86	441	98	20	27.3	4.4	20	24.9	9.9	20	40.2	9.4
		F	11	505	80	449	96	11	24.7	5.1	11	17.8	4.1	11	35.6	8.0
	■	M	43	593	95	446	78	21	27.0	4.4	40	23.8	9.7	42	42.2	10.0
		F	34	514	82	455	79	11	24.7	5.1	34	21.8	7.9	32	35.2	9.4
1988	★	M	57	562	81	435	59	57	26.6	3.8						
		F	32	491	65	424	80	32	25.1	5.3						
	■	M	72	571	85	440	62	66	26.8	3.7				8	39.3	6.5
		F	39	500	64	425	76	36	25.3	5.3				9	29.0	7.2

All subjects were identified by a talent search at age 13 and subsequently enrolled in a summer academic program for the gifted at Iowa State University (ISU). Students qualified for this program if, as seventh graders, they earned scores of at least 500 on the mathematics SAT (SAT-M) or 430 on the verbal SAT (SAT-V). Only students with SAT-M $\geq$ 350 (roughly the top 2% in mathematical reasoning ability) are included here. (Note that the group of students who took all of the tests is also included in the group who took at least one test.) ISU's Talent Search is particularly noteworthy because it has the highest participation rate in the nation (more than 75% of all eligible students) and the highest ability scores. Students in these programs tend to be (personally) motivated and (family) supported: Except for limited-income families, parents pay for them to attend. Tests: College Board Scholastic Aptitude Test (mathematics = SAT-M, verbal = SAT-V; for participants beyond the seventh grade, SAT scores were adjusted downward 4 points/month); Raven's Progressive Matrices (Advanced), a nonverbal measure of general intelligence; Vandenberg Test of Mental Rotations, a test designed to assess the ability to conceptualize and manipulate 3-dimensional objects mentally; Bennett Mechanical Comprehension Test (Form AA), a test designed to assess inferences based on primitive kinds of physical mechanisms (gears, pulleys, springs, etc.); Allport, Vernon, and Lindzey (1970) Study of Values, a measure designed to assess the relative intensity of six "evaluative attitudes" used to approach life: theoretical, aesthetic, social, economic, religious, and political.

Table 10.2. Preference Profiles of Mathematically Gifted Students Attending a Summer Academic Program Across Five Separate Years by Gender

YEAR		GENDER	N	STUDY OF VALUES											
				THEORETICAL		SOCIAL		ECONOMIC		AESTHETIC		POLITICAL		RELIGIOUS	
				$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
1992	★	M	72	46.7	7.1	35.7	6.8	43.7	7.1	36.7	7.1	44.0	6.7	33.2	10.9
		F	45	41.5	8.2	44.0	7.4	39.3	6.7	43.6	6.7	37.4	5.9	34.2	10.0
	■	M	73	46.7	7.1	35.7	6.8	43.6	7.1	36.6	7.1	44.0	6.7	33.5	11.0
		F	45	41.5	8.2	44.0	7.4	39.3	6.7	43.6	6.7	37.4	5.9	34.2	10.0
1991	★	M	68	47.7	7.0	37.1	7.3	41.6	7.2	36.4	8.2	42.9	6.6	34.2	10.4
		F	51	42.0	6.8	43.2	8.1	37.8	6.9	42.6	7.1	39.0	7.2	35.4	10.2
	■	M	77	47.6	6.9	37.1	7.0	41.8	6.9	36.5	8.3	43.1	6.8	33.8	10.1
		F	57	41.7	7.0	43.8	8.3	37.5	7.0	42.8	7.5	38.7	7.0	35.6	10.3
1990	★	M	69	46.6	8.8	38.4	7.8	40.4	8.2	38.4	8.4	42.5	6.9	33.4	11.4
		F	48	40.3	8.0	44.0	8.0	35.8	7.1	42.1	6.4	40.1	6.7	37.5	8.1
	■	M	73	46.6	8.7	38.3	7.6	40.4	8.1	37.8	8.7	42.7	6.8	33.9	11.3
		F	51	40.7	8.0	43.6	8.1	35.3	7.2	42.8	7.1	40.1	6.6	37.1	8.4
1989	★	M	20	49.3	7.4	35.4	5.9	40.3	9.4	37.3	8.0	45.0	7.8	30.8	11.1
		F	11	39.0	9.1	42.3	9.1	41.1	9.6	40.6	5.2	40.4	9.3	36.6	12.5
	■	M	43	50.0	6.8	34.8	7.5	42.2	8.2	37.0	7.7	44.1	8.2	30.9	10.7
		F	34	41.8	7.4	41.2	8.3	39.6	7.7	43.9	8.2	39.2	7.2	34.3	10.9
1988	★	M	57	48.0	8.5	34.4	7.8	44.9	7.6	35.3	8.1	45.2	8.2	32.4	12.8
		F	32	42.3	7.5	40.7	8.0	38.2	7.5	43.6	8.4	40.1	6.2	34.9	10.3
	■	M	61	48.3	8.5	34.5	7.6	44.7	7.4	35.0	8.0	44.8	8.3	32.9	12.7
		F	33	42.5	7.4	40.9	8.0	38.0	7.5	43.4	8.4	40.0	6.2	35.2	10.2

critical for engineering and physical science achievement and excellence. These differences in specific abilities contribute to the well-known gender differences at all points on the math/science pipeline, but other factors combine with specific abilities to increase the disparity between the genders.

Table 10.2 contains preference data on the same mathematically gifted subjects. Mathematically gifted males possess a tenacious commitment to a theoretical point of view. Gifted females, on the other hand, possess a more balanced value profile; they value social and aesthetic pursuits more highly than the theoretical sentiment so indicative of their male counterparts (although the theoretical scores are elevated for the females relative to their gender). Similar conclusions emerge from the interest pattern of mathematically gifted subjects. Table 10.3 provides data from Cohort 2 on the six Holland themes. The females, again, are relatively evenly distributed across artistic, investigative, and social interests, whereas the males are centrally focused on the investigative interest and (secondarily) on realistic interests for working with things.

The above gender-related patterns have been observed over decades in both normative (Stanley et al., 1992) and gifted samples (Lubinski & Humphreys, 1990a)—including all four SMPY cohorts over the past 20 years. From these profiles, gifted females would be anticipated to be relatively equally committed to educational and career tracks involving aesthetic (forms of self-expression), social (interpersonal contact), and theoretical (scientific/technical) domains. In contrast, the males should be expected to be inordinately represented all along the math/science pipeline. Interestingly, both males and females are comparatively low in their religious orientation, which is typical for scientists in general.

Table 10.3. Holland's Themes of Mathematically Precocious 13 Year-Olds, by Gender

	N	Realistic	Investigative	Artistic	Social	Enterprising	Conventional
Females	83	45.7	53.0	50.8	45.1	44.5	49.2
Males	202	49.8	54.0	42.0	41.1	47.0	51.3

7.5 < S.D. < 8.5

Male/female profiles of Holland's themes of vocational interests compiled from subjects in Cohort 2.

Longitudinal Data

The following data relate to some critical educational and vocational covariates of the aforementioned ability/preference personal attributes. Table 10.4 provides longitudinal data from Cohort 1 on the educational achievements and aspirations of our mathematically talented subjects collected at age 23. Although males and females are equally likely to have earned or aspire to advanced degrees, males far outnumber the females in engineering and physical science areas, particularly at the doctoral level. Among our mathematically gifted subjects, eight times as many males as females are choosing to earn doctorates in engineering, mathematics, or physical science (cf. Lubinski & Benbow, 1992). Similar longitudinal data were obtained in our more able samples, Cohorts 2 and 3 (Benbow & Lubinski, 1992). Among students in Cohort 2 (individuals with mathematical abilities in at least the top .5% of the ability range), 12% of the females compared to 27% of the males were pursuing doctorates in mathematics, engineering, or physical science. Moreover, the results of the age 18 survey of Cohort 3 indicated that 77% of males and 47% of females who had earned at least a 700 on SAT-M before age 13 (top 1% in 10,000 in mathematical reasoning ability) were pursuing bachelor degrees in those areas.

Table 10.4 seems to indicate as well that it is not the scientific aspect of the physical sciences that turns off females (they are well represented in biology and medicine), but rather, as one would infer from their profile of interests and values, it is the inorganic nature of the physical sciences that they appear to find less appealing. Gifted females, like females in general, apparently prefer educational subject matter and vocational settings where the content is organic. The "people versus things" dimension that Thorndike (1911) initially described might be more centrally defined as an "organic versus inorganic" gender differentiating parameter of educational/vocational interests (Benbow & Lubinski, in press). Interestingly, the antecedents to these career choices are manifested in contemporary samples of gifted adolescents, our Cohort 4. In our summer programs for the gifted, mathematically gifted females are divided equally between math/science courses and English/foreign language courses. Males, in contrast, are six times more likely to enroll in math/science than English or foreign languages. These data indicate that gender differences in interests and values (well in place at age 13; Lubinski & Benbow, 1992; Lubinski, Benbow, & Sanders, 1993) influence course selection when multiple choices are made available.

In conclusion, highly able males and females, when considered as

Table 10.4. Longitudinal Data for Mathematically Talented Students (Top 1%), Identified by a SMPY Talent Search at Age 13. Percentages Reflect Students' Current Level of Educational Attainment or Pursuit (at age 23) by Gender.

	Highest Degree / Major	Bachelor		Advanced Less than Doctorate		Doctorate		Total Across Degrees	
		Males	Females	Males	Females	Males	Females	Males	Females
Math and Science	Mathematics	3.4	3.5	0.3	0.7	0.5	0.0	4.2	4.2
	Engineering	16.2	7.6	7.9	3.0	3.4	0.7	27.5	11.3
	Physical Science	2.2	1.5	0.5	0.4	3.7	0.2	6.4	2.1
	Biology	2.2	5.4	0.3	0.4	1.1	1.5	3.6	7.3
	Medicine					8.7	5.9	8.7	5.9
	Social Science	4.8	6.1	0.4	2.0	1.9	0.9	7.1	9.0
	Humanities	2.5	5.0	0.1	2.4	0.8	1.7	3.4	9.1
	Law					6.4	4.1	6.4	4.1
	Business	7.1	11.1	4.5	5.0	0.8	0.7	12.4	16.8
Total	All Majors	42	52	15	17	28	17	85	86
	Math/Science Majors	24	18	9	5	18	9	51	32

Longitudinal data on achieved or intended educational credentials compiled 10-years following Cohort 1's identification at age 13.

a group, have differing ability and preference profiles. When evaluating these differences in the light of the Theory of Work Adjustment, the data inevitably lead to the prediction that highly able males and females will find personal fulfillment in differing career tracks. The psychological profiles of mathematically talented males are more congruent with studying physical science than are those of mathematically gifted females. These predictions were borne out by the longitudinal data collected by SMPY. As adults, mathematically talented males are more heavily represented in the sciences, especially the inorganic sciences, and at the highest educational levels, than their female peers.

CASE HISTORIES

In the above section we tried to accomplish two goals, to outline (a) the types of data that SMPY collects and their uses, and (b) how SMPY's theoretical model guides its investigations. To furnish a richer understanding of the achievements of mathematically talented students and how they can be understood in terms of our theoretical model, it might be useful to attach some ideographic content to the aforementioned normative statistics and trends by pulling a few case histories from our files. This will serve to exemplify how the above attributes operate within individuals.

Case 1

One 12-year-old female in Cohort 2 scored 610 on the SAT-M and 520 on SAT-V in seventh grade. Results of subsequent assessments revealed that she had high spatial and mechanical reasoning abilities (the Differential Aptitude Tests [DAT] Space Relations was 49, the DAT Mechanical Reasoning was 52), while her strongest evaluative attitude was theoretical on the SOV (Theoretical = 59 and Social = 28). The Strong Interest Inventory revealed that her Investigative theme, particularly in science and mathematics, was very high (I = 56, Science = 68, Mathematics = 65).[3] These scores would lead one to predict that she would find personal fulfillment in a scientific career. Indeed, consistent with her ability/preference

[3]Means and standard deviations for Holland's General Occupational Themes in normative samples follow (these were taken from Campbell, 1977, p. 33): Realistic (females = 45.5, 9.9; males = 54.5, 10.1), Investigative (females = 48.5, 10.1; males = 51.5 9.9), Artistic (females = 53.2, 8.9; males = 46.8, 11.0), Social (female = 51.3, 9.0; male = 48.7, 10.9), Enterprising (female = 48.1, 8.8; male = 51.9, 11.1), and Conventional (females = 50.1, 10.2; males = 49.9, 9.8).

profile, the following summer she attended SMPY's special fast-paced mathematics program, being driven by her parents a long distance each week to allow her to participate. She performed well (although not extraordinarily well) in this high-level class for mathematically gifted students. Then, at age 14, she entered Carnegie-Mellon to pursue her interests in cosmology; she wanted to prove that God did exist. Because she was so young and had not adequately sampled Advanced Placement (AP) courses or college courses on a part-time basis, the staff of SMPY registered some concern regarding her readiness for college. Despite this reasonable concern, she performed admirably at Carnegie-Mellon, graduating with six academic honors. With her earlier career goals still intact, she went on to graduate school at the University of Chicago to study astrophysics and, currently, at age 25, is pursuing postdoctoral work in that area. Although newly out of graduate school, she had authored three publications in the premier journal of her field, the *Journal of Astrophysics*. Clearly, this student confirmed the predictions forecast by TWA (based on her personal attributes) in terms of career choice.

Case 2

A second SMPY female was a 13-year-old in the early 1970s (Cohort 1) with a SAT-M score of 590 at age 13. Her DAT mechanical reasoning and space relations scores were also high, 55 on both. Her interests were found to lie in the investigative and realistic sectors of Holland's hexagon, while her strongest evaluative attitude was theoretical (T = 53) followed by political and social (P = 46, S = 45). This ability/preference profile would suggest that she would choose a quantitatively oriented career that involved some people contact. At that time (early 1970s) she was one of the most able females SMPY had identified and certainly one of the most motivated in mathematics. She participated in SMPY's first fast-paced mathematics class and completed 3.5 years of precalculus mathematics in 12 months. Subsequently, she enrolled in SMPY's special calculus class and again performed extremely well. She earned the highest score in the class on the AP Calculus BC exam administered at the end of the program, scoring 192 points out of a possible 210. She reported loving applied math and dreamed of one day entering MIT. At age 17, however, she entered the University of Michigan to pursue a degree in computer science, a degree which she readily completed. She subsequently married and, shortly thereafter, obtained a master's degree in computer science, earned by attending night school. A few years later she returned to school to obtain a MBA, and is currently working for a financial service company in her hometown. This choice of a career allowed her to fulfill her need to work with numbers and with people, needs which became evident at age 13 when SMPY tested her preferences.

Case 3

An exceptional boy was brought to our attention at age 9, at about the same time we were working with the female noted above. He had been tested by a school psychologist, using the 1937 Stanford-Binet Intelligence Scale (which is appropriate for this high ability level), and earned an IQ of 190. Two years later, at age 11, he took the Preliminary Scholastic Aptitude Test (PSAT); his PSAT score was 75 on Math and 53 on Verbal. (Note: it has been our observation that verbal ability, as assessed by the SAT/PSAT, develops more slowly than mathematical reasoning ability, with few high scores earned by young children.) At age 10, he completed the Holland's Occupational Checklist, showing interest in investigative followed by artistic careers. His strongest evaluative attitude on the SOV was theoretical (T = 54) followed by political (P = 47). Given his exceptional level of general intellectual ability, the staff of SMPY created the very first fast-paced mathematics class, called "Wolfson I" in honor of its capable instructor, in an attempt to meet this gifted child's educational needs. After making all of the arrangements for setting up the class, he decided that he did not want to attend. Subsequently, however, he did decide to enroll in our second fast-paced mathematics class, which started 1 year later. He performed well in that class and then went on to attend SMPY's special calculus class. At age 11, upon completion of the calculus class, he took the AP Calculus BC exam and earned a score of 4, which is comparable to having earned an A in a 1-year college calculus course. At age 12 he entered an academically rigorous and selective private high school. Although young, he performed well and graduated 30th in his class of 90 students. He then came to Johns Hopkins at age 14 and had a bad start. In his first course, freshman chemistry, he earned a D. The instructor saw him as far too bright for such a grade and made him retake the course, which he did successfully. Thereafter, things seem to proceed more smoothly and he graduated, Phi Beta Kappa, at age 18 with a major in the humanities. The following fall he entered the University of California-Berkeley Law School, from which he graduated first in his class at age 21. He then went to Stockholm on a 1-year Fulbright award, where he studied International Law and again graduated first in his class. At this point in his career, he felt that some applied experiences might be useful. Thus, he became a clerk for a Circuit Court Judge in Washington, DC for one year. Since he was still only 24 when his clerkship ended, he was eligible for a Marshall scholarship. As a Marshall scholar, he studied philosophy at Jesus College in Oxford, England. While working toward his D. Phil., he taught British Constitutional Law full time at Oxford University. At age 28 he should be completing his degree there. He now wishes to join a Law School faculty and eventually to become a Supreme Court Judge. Reflecting upon this exceptional young man's profile, one can readily comprehend how his educational/career choices are in correspondence with his abilities and preferences. At age 10 he liked to deal with abstract content involving political themes, and his verbal abilities are highly developed.

Case 4

At the same time that we were working with the last two students, another came to our attention. This young man also had an extremely high IQ, a score of 212 on the 1937 Stanford-Binet Intelligence Scale. At age 11, he earned an SAT-M of 730 and an SAT-Verbal of 440. One year earlier, at age 10, he scored a 53 on the DAT Mechanical Reasoning test and 43 on the DAT Spatial Relations test. When he completed the Strong, his primary theme was conventional (65), while on the Study of Values his highest score was for theoretical (51), followed by social and economic (45 and 44, respectively). This is not a typical preference profile for our gifted subjects, particularly the high conventional score. These results would predict some difficulty in the career decision-making process for this young man. There are few conventional careers, his primary career interest theme, that this young man would find challenging. He enrolled in our first fast-paced mathematics class and successfully completed 4.5 years of mathematics in 14 months. After this initial success, however, things did not proceed so well. Although he enrolled in a night class in calculus at Johns Hopkins, he earned a D in the class, partly because he traveled with his father for one month during the semester. Moreover, even though this young man graduated from a parochial high school at age 14, he did not perform academically anywhere near his potential. Apparently, the well-meaning faculty at the high school were so impressed by the boy, whom they considered a genius, that they allowed him to slack off (Julian C. Stanley, 1991, personal communication). Unfortunately, this newly acquired behavior did not change. He entered Johns Hopkins at age 14, but left during his third year. He would not do any work or attend classes. He subsequently transferred to a much less selective school and changed his major from economics to geography. After college graduation, he worked as a paralegal and attended law school at night. At age 28 he completed law school and subsequently joined a good law firm. Again, the pattern of choices, although not the level of achievement, was congruent with this young man's ability/preference profile.

Detailing the individual case histories not only provides a richer appreciation of the nature of intellectual giftedness, it also reveals the unique paths that the gifted choose to traverse. Such students tend to achieve highly (Benbow, 1992; Lubinski & Benbow, 1992; Lubinski & Humphreys, 1990a; Swiatek & Benbow, 1991a, 1991b), but not necessarily in a smooth or normatively sequenced fashion. Each chooses to develop his or her high potential in different ways. Intentions and plans are implemented and terminated in idiosyncratic developmental trajectories containing an appreciable component of chance (Lubinski, Benbow, & Sanders, 1993; Tannenbaum, 1983). It appears that many gifted students (not unlike their less able peers) frequently try many disciplines (educational/vocational tracks) before their abilities and preferences hit upon an environmental ecology whose response requirements and reward structure is of sufficient correspondence to motivate the kind of commitment necessary for truly remarkable academic achievements. More often than not, however, the final career choices seem to be in correspondence with abilities and preferences.

IMPLICATIONS: STEPPING BACK

Among Terman's (1925-1957) most noteworthy contributions to the field of intellectual giftedness was his documentation of the central importance of *general intelligence* ("*g*"), or the communality cutting across all forms of cognitive tests. In another context, Schmidt and Hunter (1992; Schmidt, Ones, & Hunter, 1992) have convincingly revealed that general intelligence accounts for approximately 50% of the variance in a variety of work-performance criterion behaviors. But it was not until the 1980s that our methodological sophistication was such that artifacts could be controlled to reveal just how psychologically significant the construct of general intelligence actually is. In the words of Meehl (1990): "Almost all human performance (work competence) dispositions, if carefully studied, are saturated to some extent with the general intelligence factor *g*, which for psychodynamic and ideological reasons has been somewhat neglected in recent years but is due for a comeback [cf. Gottfredson (1986)]" (p. 125).

The construct of general intelligence was never underappreciated by Stanley (1977) when he assembled the edifice of SMPY. But

Stanley did stand on Terman's shoulders. The core of general intelligence is profitably assessed by the communality running through verbal/linguistic, numerical/quantitative, and spatial/mechanical tests. Stanley wondered if tests concentrating on each symbolic/representational system might have differential validity for scientific achievement among the gifted. He focused on mathematical reasoning ability and, over the past 20 years, documented that, even in gifted samples, it is indeed useful to conduct more differentiated assessments of the intellectual repertoire than those conducted by Terman. Among the gifted, marked discrepancies in verbal abilities over quantitative abilities result in highly verbal educational and subsequent career tracks (e.g., law, philosophy, journalism), whereas the inverse pattern is more typical of engineers and physical scientists (Benbow, 1992b; Humphreys et al., 1993). Whatever innovations future longitudinal researchers bring to the area of giftedness, they would do well to model Stanley.

Stanley did not reject the power of the construct of general intelligence, he appreciated it, assimilated it, and measured his innovations against what Terman had achieved. This is how his contribution was measured. And his out-of-level assessments conducted through SMPY and now nationally in other research programs are appreciably more sophisticated and systematic than Terman's earlier work. He did not "bash" Terman, he refined him. Future researchers seeking to uncover other kinds of intellectual talent or measures of known aspects of intellectual talent would do well to measure their creations against existing techniques. In this way, the precise magnitude of new contributions can be appraised in the clearest possible light. Paradigm shifts are best accomplished by those who understand the strengths and weaknesses of the normal paradigms that, currently, best explain the variance that we are interested in. Our suggestion for where to look next is within the context of normal science, but, while not wholly innovative, should hold substantial dividends for future researchers.

The SMPY model has systematically selected participants for longitudinal tracking based on their quantitative and/or verbal precocity. Spatial/mechanical reasoning abilities have not been used for identification. Moreover, such abilities are correlated in the low .60s with mathematical reasoning abilities (Lubinski & Humphreys, 1990b) and in the low .50s for verbal ability. For individuals in the top 1% of spatial/mechanical reasoning abilities, approximately half will be below 93% in mathematical reasoning ability and thus missed by talent searches following the SMPY model. Many more than half will be below this value in verbal ability. One of our greatest untapped resources for the math/science pipeline, students with high spatial/mechanical reasoning abilities, are often disqualified for advanced training in the physical sciences because of their relatively low levels of mathematical or verbal ability. Such students might be especially intriguing to follow longitudinally. They might also be difficult to aggregate for assessment, inasmuch as they tend to be rather inconspicuous personologically and come from lower SES levels relative to the mathematically and verbally gifted.

CONCLUSION

In summary, the Study of Mathematically Precocious Youth (SMPY) is a planned 50-year longitudinal study, which is currently in its third decade. A theoretical model for guiding and organizing our educational and vocational longitudinal research, the Theory of Work Adjustment (TWA), was elaborated. To supply some context for these descriptions, data were provided, based on inferences drawn from TWA, which speak to the discrepant male/female ratio of achieved educational credentials in engineering and the physical sciences, and which appraise the verisimilitude of this model. It was suggested that contemporary researchers assimilate what is known about the nature and organization of human abilities when evaluating the conservation, development, and optimal utilization of different kinds of precocious talent.

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