Part V
Trajectories

The Wiley Handbook of Genius, First Edition. Edited by Dean Keith Simonton.

19

The Study of Mathematically Precocious Youth at Maturity

Insights into Elements of Genius

Harrison J. Kell and David Lubinski

Genius, by definition, is rare. It is arguably the rarest phenomenon in the human condition. In Murray's (2003) compelling analysis, *Human Accomplishment*, he suggests that genius is indicative of individuals who generate products that transform humanity. When leaders in the field examine the creative contributions generated by geniuses, their response is frequently "How could a human being have done that?"

If we set the bar high enough, limiting discussions of genius to luminaries such as Shakespeare and Dante, Einstein and Newton, or Aristotle and Plato, a list of around 100 individuals for all time is likely to eventuate. Therefore, one may reasonably ask, as Dean Simonton does in the preface to this volume, "Can such a rare phenomenon be studied scientifically?" To study a group of 100 individuals scientifically who were born across a range of 2,000 years is mindboggling. If standards are lowered, however, to, say, Murray's (2003) list of the top 20 contributors to 20 major disciplines (e.g., medicine, music, physics), this facilitates matters. Yet even with this more liberal approach, the scientific study of genius is still exceedingly difficult – it would leave us with about 400 individuals stretched over approximately 2,800 years, suggesting a *single* genius arises, on average, only *once* every seven years! This still understates the problem, however, as the emergence of genius is not evenly distributed over time; certain historical periods abound in the production of genius while others lie fallow (Murray, 2003).

Perhaps a more manageable approach is to focus on the scientific study of populations from which genius is most likely to emerge. These populations can be identified according to whether their constituents possess the characteristics that have been found to be necessary – although not sufficient – for genius. One characteristic that has been associated with the idea of genius nearly since its inception is exceptional intelligence (Eysenck, 1995).

This chapter explores the phenotypic manifestations of exceptional intelligence. It details several major life outcomes of over 3,000 individuals, all within the top 1% of cognitive ability (Lubinski, 2009; Lubinski & Benbow, 2006), as well as a cohort of top math/science graduate students identified at age 25 and tracked for over a decade

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(Ferriman, Lubinski, & Benbow, 2009; Lubinski, Benbow, Shea, Eftekhari-Sanjani, & Halvorson, 2001; Lubinski, Benbow, Webb, & Bleske-Rechek, 2006). It further uses a model of talent development articulated (Lubinski & Benbow, 2000, 2001, 2006) and applied (Benbow, 1992; Kell, Lubinski, & Benbow, 2013; Kell, Lubinski, Benbow, & Steiger, 2013; Park, Lubinski, & Benbow, 2007, 2008) over the past three decades to organize what is known about several lifelong relatively stable psychological characteristics, that is, cognition, affect, and conation, all known determinants of individual differences in learning, work, and creative expression and, at extreme levels, characteristics of genius (Eysenck, 1995; Galton, 1869). We offer this talent development framework as a tool for facilitating understanding of the kinds of personal attributes to consider for identifying exceptional promise – and for understanding the niches wherein genius is spawned. When multiple personal characteristics are needed, and they are all needed at exceptional levels (plus they are relatively uncorrelated), rare segments of the population are expressly isolated by teaming valid measures of key determinants. These are the small segments of humanity that have outstanding promise for remarkable accomplishments – when opportunity (the appropriate niche) is available.

The Study of Mathematically Precocious Youth

An ongoing longitudinal study begun in 1971 by Julian C. Stanley (1996) at Johns Hopkins University, the Study of Mathematically Precocious Youth (SMPY) consists of five cohorts of individuals distinguished by their high cognitive abilities. Now codirected by Camilla P. Benbow and David Lubinski at Vanderbilt University, SMPY began by using talent searches to identify young adolescents who reasoned exceptionally well mathematically and sought to find better ways to facilitate their educational development (Benbow & Stanley, 1983; Stanley, 1996). Then, over time, SMPY selection criteria were augmented to include verbal abilities and, in 1992, added a cohort of first- or second-year graduate students in top-ranked biochemistry, physical science, engineering, or mathematics programs in the United States (Lubinski & Benbow, 2006; Lubinski, Benbow, Shea, Eftekhari-Sanjani, & Halvorson, 2001). As participants entered adulthood, SMPY's emphasis shifted from educational outcomes (Achter, Lubinski, Benbow, & Eftekhari-Sanjani, 1999; Benbow, 1992) toward occupational development and outcomes in the world of work (Lubinski & Benbow, 2000; Shea, Lubinski, & Benbow, 2001; Wai, Lubinski, & Benbow, 2005; Webb, Lubinski, & Benbow, 2002). More recently, SMPY has turned to the study of creativity, eminence, and leadership among its participants at midlife (Kell, Lubinski, & Benbow, 2013; Kell, Lubinski, Benbow, & Steiger, 2013; Park *et al.*, 2007, 2008).

Conceptualizing Talent Development

To scientifically study rare human phenomena, identifying populations at promise is a necessary first step. If, for example, a group of developmental psychopathologists was interested in studying schizophrenia longitudinally, a random sample of 1,000 children in the U.S. population would only capture around 10 individuals who ultimately go on to develop this condition (the same would be true for manic-depressive disorders). The likelihood or base rate would be much rarer for truly outstanding accomplishments in science, technology, engineering, and mathematics (STEM), where a constellation of exceptional talent (general intelligence, mathematical, and spatial abilities), preferences profiles defined by scientific/theoretical interests and values, and the personal passion and resources for working over protracted intervals (often in isolation) is essential (Lubinski *et al.*, 2001, 2006). Identification is the first step for finding populations "at promise," and the model found in Figure 19.1 has documented verisimilitude for making this move.

Figure 19.1 is an adaptation of the Theory of Work Adjustment (Dawis & Lofquist, 1984; Lubinski & Benbow, 2000). It organizes this treatment by outlining dimensions of human individuality critical for performance in learning and work environments, as well as transitioning between them. It assembles the dominant models of intellectual abilities and educational-occupational interests, and links them to corresponding features of learning and work environments (ability requirements and reward structures,

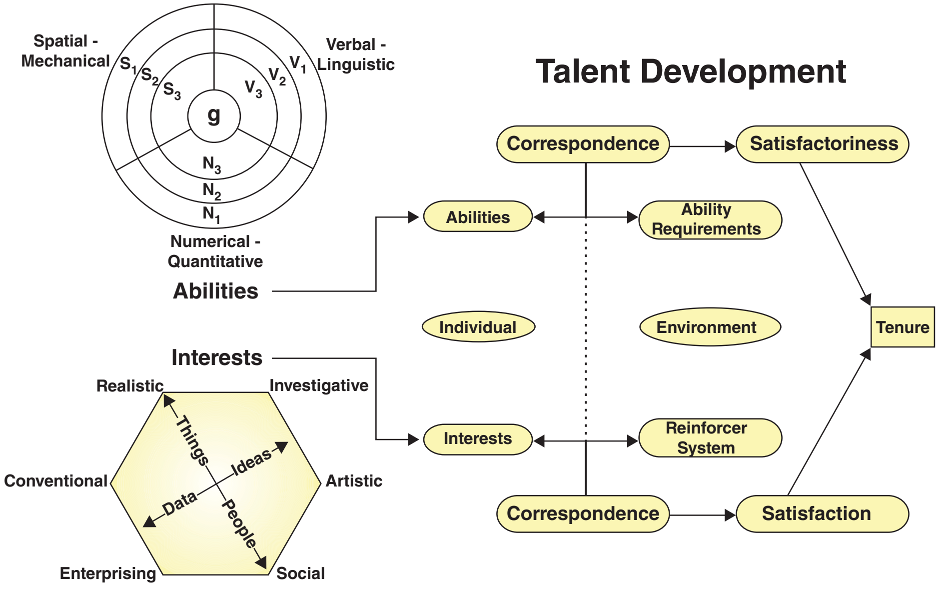

Figure 19.1 Adaptation of the Theory of Work Adjustment (Dawis & Lofquist, 1984) following Lubinski and Benbow (2000) to highlight its general role in Talent Development over the lifespan. The radex scaling of cognitive abilities (upper left) and the RIASEC hexagon of interests (lower left) outline personal attributes relevant to learning and work. The letters within the cognitive ability arrangement denote different regions of concentration, whereas their accompanying numbers increase as a function of complexity. Contained within the RIASEC is a simplification of this hexagon. Following Prediger (1982), it amounts to a two-dimensional structure of independent dimensions: people/things and data/ideas, which underlie RIASEC. The dotted line running down the individual and environment sectors underscores that equal emphasis is placed on assessing personal attributes (abilities and interests) and assessing the environment (abilities requirements and reward structure). Correspondence between abilities and ability requirements constitutes satisfactoriness, whereas correspondence between interests and reinforcer systems constitutes satisfaction. Jointly, these two dimensions predict tenure or a longstanding relationship between the individual and the environment. Reproduced by permission of the American Psychological Association.

respectively), which set standards for meeting expectations (credentials) and rewarding valued performance (compensation). Correspondence between abilities and ability requirements constitutes satisfactoriness ("competence," or valued performance), whereas correspondence between interests and reward structures constitutes satisfaction ("fulfillment," or personal well-being). When satisfactoriness and satisfaction co-occur, individuals are motivated to maintain contact with the environment and the environment is motivated to retain those individuals; if one of these dimensions is dis-correspondent, individuals are motivated to leave the environment or likely to be dismissed from it.

This talent development model places equal emphasis on assessing individuals and the environments they inhabit – as might be expected, given it was originally developed within counseling psychology (Dawis & Lofquist, 1984). Comprehensive reviews of outcomes within education (Lubinski, 1996; Lubinski & Benbow, 2000), counseling (Dawis, 1992; Gottfredson, 2003; Rounds & Tracey, 1990), and industrial/organizational psychology all emphasize this person/environment tandem (Dawis, 1991; Katzell, 1994; Lubinski & Dawis, 1992): aligning competency/motivational proclivities to performance standards and reward structures (Bouchard, 1997; Lubinski, 2010; Scarr, 1996). For making individual decisions about personal development, or institutional decisions about organizational development, it is useful to move beyond the minimalist approach of "do you like it" (satisfaction) and "can you do it" (satisfactoriness) and instead consider what individuals like the most *and* can do the best (Lubinski & Benbow, 2000, 2001). This framework is useful for identifying "optimal promise," and for understanding those rare populations comprising individuals who expand knowledge frontiers and can sometimes even change cultures.

Cognitive Abilities

Over the last two decades, a consensus has emerged that cognitive abilities are organized hierarchically (Carroll, 1993). An outline of this hierarchy is represented by the radex (Guttman, 1954), depicted in the upper-left region of Figure 19.1. This illustrates that cognitive ability assessments covary as a function of their content or complexity (Corno *et al.*, 2002; Lubinski & Dawis, 1992; Snow, Corno, & Jackson, 1996). Cognitive ability tests can be scaled in this space based on how highly they covary with one another. The more two tests share complexity and content, the more they covary, and the closer they are to one another as points within the radex. Test *complexity* is scaled from the center of the radex ("*g*") out, and, along lines originating from the origin, complexity decreases, but test content remains the same. Test *content* is scaled around the circular bands with equal distance from the center of the radex, and, progressing around these bands, test content changes from spatial/mechanical to verbal/linguistic to quantitative/numerical, but test complexity remains constant. Therefore, test content varies *within* each band (but complexity remains constant), whereas test complexity varies *between* bands (but on lines from the origin to the periphery, content remains constant). Because the extent to which tests covary is represented by how close together they are within this space (Lubinski & Dawis, 1992; Snow *et al.*, 1996; Wai, Lubinski, & Benbow, 2009), this model is helpful in organizing the many different kinds of specific ability tests.

The radex highlights the content and sophistication of thought applied to familiar and novel problem-solving tasks. Mathematical, spatial, and verbal reasoning comprise the chief abilities with implications for choosing among learning and working settings and later performance in those settings (Corno *et al.*, 2002; Dawis, 1992, 1996, 2001; Gottfredson, 2003; Lubinski, 2004; Wai *et al.*, 2009). The content of these specific ability assessments indexes individual differences in different modalities of thought: reasoning with numbers, words, and figures or shapes. Despite their disparate content, specific ability tests are all positively correlated, because they all measure an underlying property of human thought.

This general dimension was identified over 100 years ago (Spearman, 1904) and has been corroborated by a massive quantity of subsequent research (Carroll, 1993; Jensen, 1998) and is known as *general mental ability*, the *general factor*, or simply *g* (Gottfredson, 1997). General mental ability represents the complexity/sophistication of a person's intellectual repertoire (Jensen, 1998; Lubinski & Dawis, 1992). The more complex a test is, regardless of its content, the better it measures *g*. Moreover, because *g* underlies all cognitive reasoning processes, any test that assesses a specific ability is also a measure of *g* to some extent (Lubinski, 2004). In school, work, and everyday life, assessments of this general dimension covary more broadly and deeply than any other measure of human individuality (Hunt, 2011; Jensen, 1998; Lubinski, 2000, 2004).

g manifests its universal importance beyond educational settings (where it covaries .70–.80 with scores on achievement tests) by playing a role in shaping phenomena within Freud's two important life domains: *lieben* (loving) and *arbeiten* (working). *g* covaries .20 to .60 with work performance as a function of job complexity, .30–.40 with income, –.20 with criminal behavior, .40 with socioeconomic (SES) status of origin, and .50–.70 with achieved SES, while assortative mating correlations on *g* are around .50 (Jensen, 1998; Lubinski, 2004; Schmidt & Hunter, 1998). Further, the idea that, after a certain point, more ability does not matter (i.e., the threshold hypothesis; Gladwell, 2008) is not supported by empirical evidence: More ability *does* matter.

Although other personal determinants must be taken into account (i.e., interests, persistence), in settings conducive to learning, working, and creating, *ceteris paribus*, more ability is better; this is true even among those in the top 1% of ability, whose IQ equivalents range from approximately 137 to over 200 (see Figure 19.2). When appropriate assessment and criterion measures are utilized to capture the breadth of ability and accomplishment, individual differences within the top 1% of ability are shown to matter a great deal. In the past, these differences have been obscured because intellectual assessments and criterion measures applied in intellectually talented populations lacked sufficient scope, which resulted in attenuated variance in assessments among the able and exceptionally able (i.e., ceiling effects). Without variation, there can be no covariation. More recent investigations have recognized and corrected for these shortcomings (e.g., Benbow, 1992; Kell, Lubinski, & Benbow, 2013; Lubinski, 2009; Park *et al.*, 2007, 2008), allowing for a better appreciation of the practical and theoretical significance of individual differences in cognitive ability within the top 1%.

Kell, Lubinski, and Benbow (2013) recently provided further evidence falsifying the idea of an ability threshold. They examined the life accomplishments, to age 38, of 320 individuals identified as being in the top 0.01% (i.e., top 1 in 10,000) of general ability (IQs $\geq$ 160) before age 13. This sample constitutes the largest number of individuals

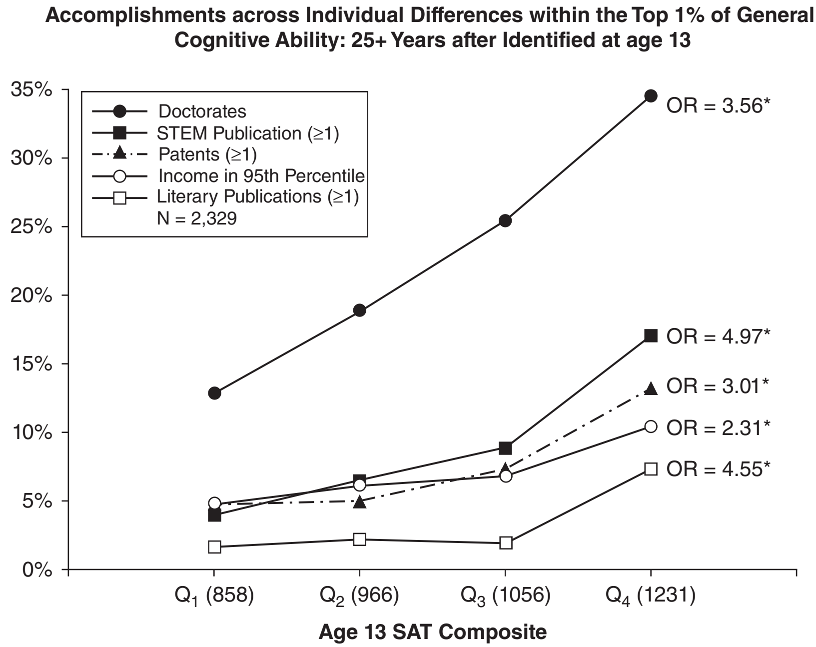

Figure 19.2 Likelihood of accomplishment outcomes across individual differences in the top 1% of mental ability. Participants are separated into quartiles based on their age 13 SAT-M+SAT-V Composite. The mean age 13 SAT Composite score for each quartile is displayed in parentheses along the *x*-axis. Odds ratios comparing the likelihood of each outcome in the top (Q4) and bottom (Q1) SAT quartiles are displayed at the end of each respective criterion line. An asterisk indicates that the 95% confidence interval for the odds ratio did not include 1.0, meaning that the likelihood of the outcome in Q4 was significantly greater than in Q1. These age 13 SAT assessments were conducted before the recentering of the SAT in the mid-1990s (i.e., during the 1970s and early 1980s); at that time, cutting scores for the top 1 in 200 were SAT-M ≥ 500, SAT-V ≥ 430; for the top 1 in 10,000, cutting scores were SAT-M ≥ 700, SAT-V ≥ 630 by age 13. Adapted from Lubinski (2009). With kind permission from Springer Science and Business Media.

at this ability level whose educational, occupational, and creative accomplishments have been studied scientifically (Lubinski, Webb, Morelock, & Benbow, 2001). As indicated by the information presented in Table 19.1, their accomplishments over 25 years following their identification are stunning. By means of benchmarking, 2% of the United States population (of all ages) holds a doctoral degree (e.g., JD, MD, Ph.D.; U.S. Census Bureau, 2012) and 23% of individuals in the top 1% of ability hold doctoral degrees (Lubinski & Benbow, 2006) – yet within this sample of individuals in the top 1 in 10,000, 44% held doctoral degrees. Moreover, they were approximately twice as likely to secure those degrees from elite educational institutions.

Along the same lines, 1% of the general American population holds a patent, compared with 15% of these 320 people. Their occupational accomplishments were also extremely impressive. For example, by age 38, over 11% of participants held tenure at a university – and over 7% at a research-intensive one. Outside academia, participants were regularly found in some of the most cognitively demanding occupations

Table 19.1 Details on participants' creative accomplishments and caliber of organizations granting major awards to participants by age 38. Adapted from Kell, Lubinski, and Benbow, 2013.

Creative accomplishments	*Award-granting agencies and organizations*
Arts & Humanities[a]	
Dance productions (7, 5, 1–20, 50)	
Music productions (21, 8, 1–500, 872)	American Lung Association
Non-fiction books (6, 1, 1–3, 10)[b]	American Political Science Society
Novels (2, 5, 1–9, 10)[b]	American Society of Agricultural Engineers
Paintings (7, 2, 1–60, 70)	Chrysler Group
Poems (5, 1, 1–34, 39)	Emory University
Refereed publications (6, 3, 2–15, 39)	General Electric Company
Sculptures (3, 1, 1–4, 9)	General Motors Company
Short stories/Dramatic plays (5, 1, 1–25, 30)	IBM
Theatre productions (14, 3, 1–30, 68)	Intel Corporation
STEM	International Interior Design Association
Refereed publications	Massachusetts Institute of Technology
Biochemistry (6, 2.5, 1–15, 29)	Math Association of America
Computer science (9, 3, 1–19, 45)	National Academy of Engineering
Engineering (3, 2, 2–18, 22)	NASA
Mathematics (9, 4, 1–29, 66)	National Endowment for the Humanities
Medicine (12, 6.5, 1–37, 99)	National Science Foundation
Natural sciences (5, 4, 3–8, 23)	Phi Beta Kappa Society
Physical sciences (15, 4, 1–33, 108)	Princeton University
Patents (49, 3, 1–19, 133)[c]	Society for Technical Communication
Fortune 500 patents (18, 2, 1–17, 65)	Standard Performance Evaluation Corporation
Software contributions (68, 3, 1–100, 687)	U.S. Central Intelligence Agency
Other	U.S. Department of Justice
Articles	U.S. Department of State
Essays – unknown content (9, 2, 1–25, 43)	U.S. Food and Drug Administration
Refereed publications	U.S. Marine Corps
Business (1, 6)	The Wall Street Journal
Economics/Econometrics (2, 1.5, 1–2, 3)	Zacks Investment Research
Law/Public policy (5, 3, 1–12, 21)	
Social sciences (3, 2, 1–13, 16)	
Companies founded (14, 1, 1–3, 16; $147K, $25–75K, $2M)[d]	Other organizations
Grants funded (40, 2.5, 1–12, 140)	(49, 2, 1–8, 114)[e]
Grant funding received (31, $200K, $2.7– $9000K, $26M)[d]	
Primary income (225, $80K, $1.2K–$1.4M)[d]	

Note. STEM = science, technology, engineering, and mathematics.
[a]For business publications, the values in parentheses indicate that one participant had produced six publications. For grant funding received, the values in parentheses denote (from left to right) the number of individuals reporting their amount of grant funding and the median amount, range, and total amount of grant funding aggregated across these individuals. For primary income, the numbers indicate the total number of participants reporting their primary income and the median and range of their reported income. For all other categories, the numbers inside parentheses indicate the number of individuals in the category and the median number, range, and total number of accomplishments in that category. In the case of companies founded, the numbers following the semicolon indicate the median income of those individuals who indicated that they had founded at least one company and the range of income and total income they reported. [b]The base rates for novels and nonfiction books in the United States are 0.13% and 0.46%, respectively (see Bowker, 2012). [c]The base rate for patents in the United States is approximately 1% (U.S. Patent and Trademark Office, 2011). [d]Dollar amounts are based on data collected when participants were age 33 and have not been adjusted for inflation. K = thousands; M = millions. [e]The numbers in parentheses indicate (from left to right) the total number of participants who reported receiving major awards from organizations other than those listed, the median number of such awards they received, the range of awards received, and the total number of awards received.

(Gottfredson, 2003; Hunt & Madhyastha, 2012), including engineering, surgery, and physics, supporting the notion that people tend to gravitate toward jobs that are commensurate with their intellectual capabilities (Wilk, Desmarais, & Sackett, 1995; Wilk & Sackett, 1996). Assembling these rare outcomes in tabular form reinforces the idea that, when it comes to cognitive ability, more indeed *is* better for real-world accomplishment, including being entrusted with significant responsibilities for managing and enhancing economic and social capital.

Yet, even when *g* is measured in its full scope, and validated with large samples and appropriate low-base-rate criteria over protracted intervals, there is much more to intellectual functioning than *g*; Figure 19.3 reveals how general and specific abilities operate over the course of development. It contains data from over 400,000 high-school students assessed between grades 9 and 12, and tracked for 11 years.

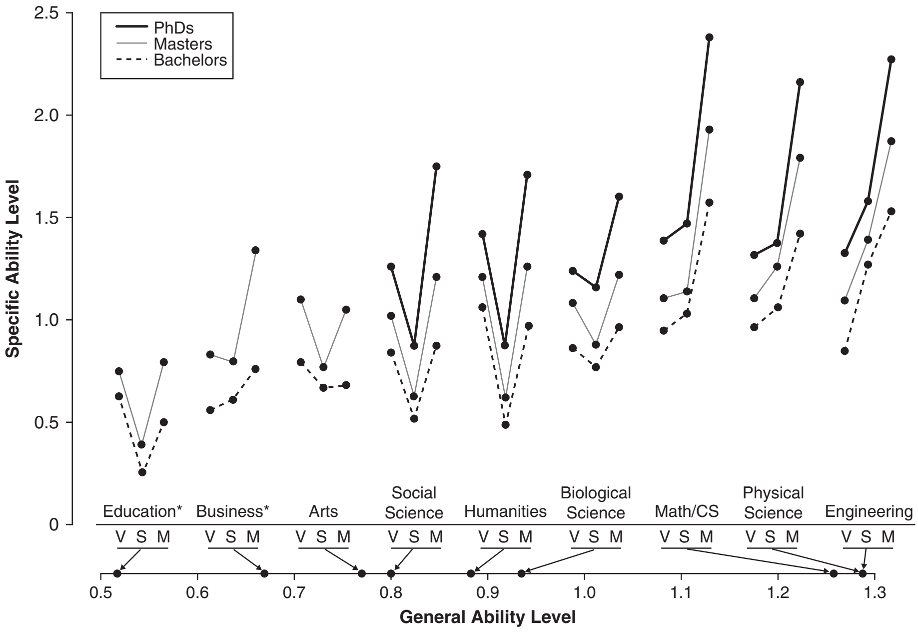

Figure 19.3 Average *z* scores of participants on verbal, spatial, and mathematical ability for terminal bachelor's degrees, terminal master's degrees, and doctoral degrees plotted by field. The groups are plotted in rank order of their normative standing on *g* (verbal [V] + spatial [S] + mathematical [M]) along the *x*-axis, and the lines with arrows from each field indicate where these disciplines average in general mental ability in *z*-score units. This figure is standardized in relation to all participants with complete ability data at the time of initial testing. Respective *N*s for each group (men + women) were as follows for bachelor's, master's, and doctorates, respectively: engineering (1,143, 339, 71), physical science (633, 182, 202), math/computer science (877, 266, 57), biological science (740, 182, 79), humanities (3,226, 695, 82), social science (2,609, 484, 158), arts (615, 171 [master's only]), business (2,386, 191 [master's + doctorate]), and education (3,403, 1,505 [master's + doctorate]). *For education and business, master's degrees and doctorates were combined because the doctorate samples for these groups were too small to obtain stability ($N < 30$). For the specific N for each degree by sex that composed the major groupings, see appendix A in Wai *et al.* (2009). Wai *et al.*, 2009. Reprinted by permission of the American Psychological Association.

Figure 19.3 graphs the general and specific ability profiles of students earning terminal degrees in nine disciplines (Wai *et al.*, 2009). Given that highly consonant results were found for all four grades, the cohorts were combined. High general intelligence and an intellectual orientation dominated by high mathematical and spatial abilities, relative to verbal ability, characterize individuals who pursued advanced educational credentials in STEM. These participants occupy a region defined by an ability level and pattern different from those who earn undergraduate and graduate degrees in other domains.

The STEM and non-STEM educational groups are distinguishable in two major ways. First, those who ultimately secure educational credentials in STEM domains score higher on the general factor than those earning degrees in other areas, especially on nonverbal intellectual abilities. In fact, within all educational domains, more advanced degree attainment is associated with higher scores on *g and* specific abilities. Second, for all three STEM educational groupings (and the advanced degrees within these groupings), spatial ability > verbal ability, whereas for all others, ranging from education to biology, spatial ability < verbal ability (business being an exception). Students who subsequently secured advanced educational credentials in STEM manifested a spatial–verbal ability pattern opposite that of those who earned educational credentials in other areas. These same patterns play out in occupational arenas in similar ways (Kell & Lubinski, in press). Over the past decade, individual differences within the top 1% of ability have revealed that these patterns are predictive of important outcomes for technical innovation and creativity, with respect to both ability level (Lubinski, 2009; Park *et al.*, 2008) and pattern (Park *et al.*, 2007; Kell, Lubinski, & Benbow, 2013; Kell, Lubinski, Benbow, & Steiger, 2013). Level of general ability has predictive validity for the *magnitude* of accomplishment (i.e., exceptionality), whereas ability pattern has predictive validity for the *nature* of accomplishments (i.e., achievement domain).

The importance of ability pattern is maintained across apparently the entire magnitude of cognitive ability and breadth of real-world achievement. Where Figure 19.3 reveals the ability pattern underlying educational attainment in the general population, Figure 19.4 reveals the ability pattern (verbal, math) underlying occupational attainment in the Kell, Lubinski, and Benbow (2013) sample of individuals in the top 0.01% of intellectual ability. Again, those whose verbal prowess was more impressive than their mathematical reasoning abilities concentrated their energies in the humanities and verbal/linguistic disciplines, whereas the inverse ability pattern characterized those who embarked on STEM careers. It is important to note that for well over 94% of the participants in this sample, their less impressive specific ability score, regardless of whether it was mathematical or verbal reasoning, surpassed the typical Ph.D. in any discipline! So, it is not that once a critical level of ability is reached, all careers are seen as equally attractive. Rather, like typical college students (Gottfredson, 2003; Lubinski, 2010; Wai *et al.*, 2009), the profoundly gifted tend to focus their energies on the domains that play to their own intellectual strengths.

Kell, Lubinski, Benbow, and Steiger (2013) provided evidence that ability pattern influences more than educational and occupational attainment – it influences creative accomplishment as well. They examined the importance of patterning of verbal, math, and spatial abilities to differentially predict creative accomplishments among individuals identified as having IQs in the top 0.5% between 1976 and 1978, when they were 13 years old. They conceptualized educational outcomes as resulting from knowledge

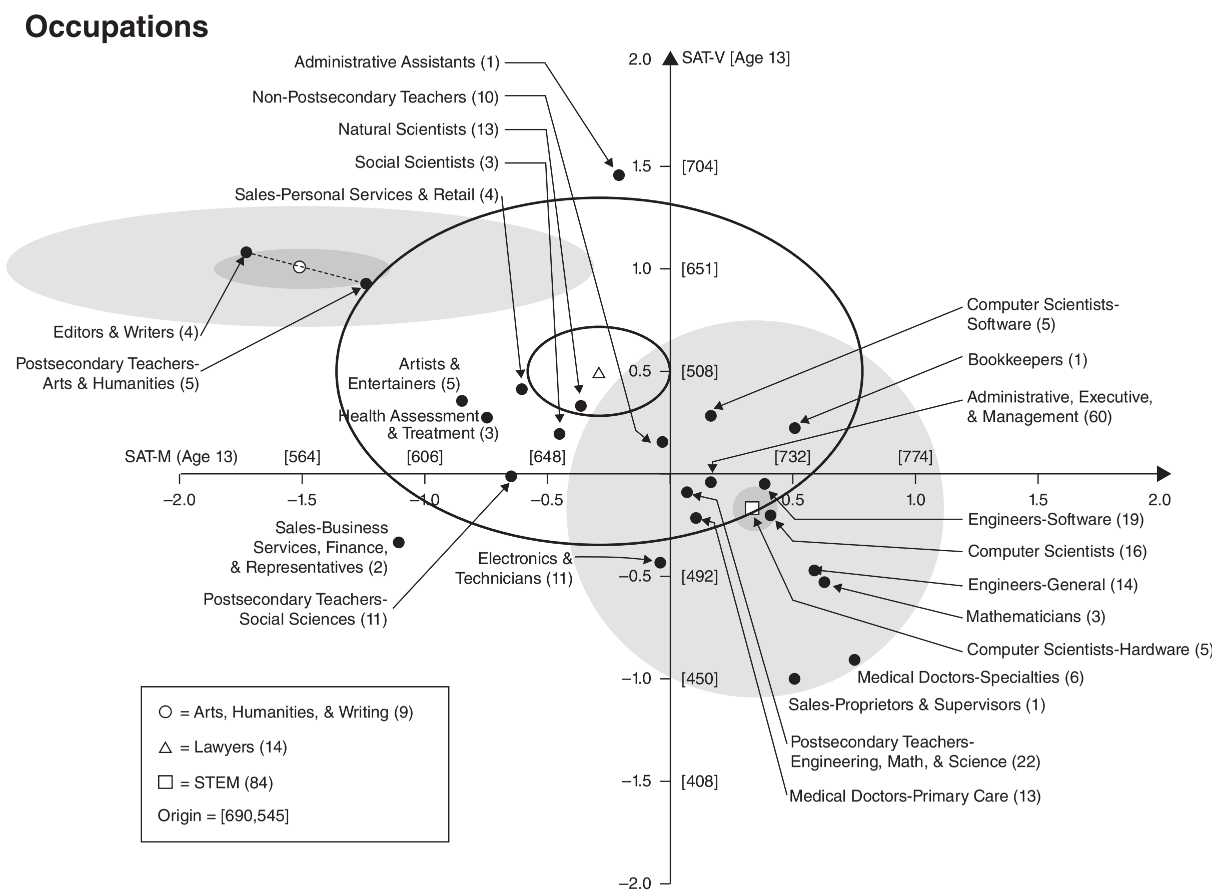

Figure 19.4 Bivariate means for age-13 SAT-Math (SAT-M; *x*) and SAT-Verbal (SAT-V; *y*) scores within occupational category (when participants were 38 years old). Means for individual occupational categories are represented by black circles; the sample sizes for these categories are in parentheses. White shapes (i.e., circle, triangle, square) represent rationally derived centroids (*n*s for these centroids are indicated in the key). The dashed lines emanating from a centroid indicate its constituents. Each centroid is surrounded by two elliptical tiers that highlight the concentration of points (gray shading or black outlines): an inner ellipse formed by the standard errors of the SAT-M and SAT-V means for that centroid (i.e., width and length = ±1 SEM for SAT-M and SAT-V, respectively) and an outer ellipse formed by the standard deviations of the SAT scores for that centroid (i.e., width and length = ±1 SD for SAT-M and SAT-V, respectively). Along the axes, unbracketed values are SAT-M and SAT-V scores in *z*-score units, and bracketed values are raw SAT scores. Adapted from Kell, Lubinski, and Benbow (2013a).

assimilation, occupational outcomes as resulting from knowledge application or utilization, and creative outcomes as being the end product of knowledge creation or innovation. Following Simonton (2012), Kell, Lubinski, Benbow, and Steiger (2013) defined creative outcomes (i.e., products) as being novel, useful, and surprising in the judgment of experts. In late 2011 and early 2012, they gathered information about participants' peer-reviewed articles and patents.

To demonstrate the importance of ability pattern for creative accomplishment, the trivariate (mathematical, spatial, verbal ability) means for the following four criterion groups were plotted in three-dimensional space: at least one refereed publication in the arts, humanities, law, or social sciences; at least one refereed publication in biology or medicine; at least one refereed publication in STEM; and, finally, at least one patent. Ellipsoidal confidence regions (i.e., three-dimensional equivalents of univariate means plus or minus one standard error) were plotted for each criterion group's trivariate mean to gain a sense of the different regions these four "types of creators" inhabit within the psychological space defined by the three abilities. Results are presented in Figure 19.5 (Plate 4) and replicate the specific ability patterns observed in educational and occupational domains. Individuals who held patents or peer-reviewed articles in STEM were distinguished by having cognitive profiles favoring spatial over verbal ability, while those with the opposite pattern evinced creativity in the arts, humanities, or social sciences. These results provide compelling evidence for the importance of ability profile for creative accomplishment, which can truly be termed an "ultimate criterion" (Thorndike, 1949).

Given longitudinal findings amassed over multiple decades, the psychological sciences have established a firm generalization: ***modeling exceptional accomplishments in education, the world of work, and creativity are destined to be underdetermined if mathematical, verbal, and spatial ability are not assessed in their full scope***. In the sciences, for example, assessing mathematical reasoning alone is insufficient (cf. Kell, Lubinski, & Benbow, 2013); the level and pattern of spatial and verbal reasoning is also essential, as are other patterns for other disciplines (Humphreys, Lubinski, & Yao, 1993; Kell, Lubinski, Benbow, & Steiger, 2013; Lubinski, 2010).

Interests

Facility does not guarantee enjoyment, and psychological information on motivational differences (i.e., personal passions) is needed to understand what attracts and repels people, different ways they can create meaningful lives, and how their differential development might unfold. Even people with the same intellectual architecture vary widely in their motivational proclivities. As noted by Plato, different horses drive human development down different life paths (cf. Burt, 1955). The lower-left region of Figure 19.1 depicts the prevailing model of vocational interests, which has developed from decades of large-scale longitudinal and cross-cultural research (Day & Rounds, 1998). It is represented by a hexagon consisting of six general themes: Realistic (R) = working with gadgets and things, the outdoors, need for structure; Investigative (I) = scientific pursuits especially mathematics and the physical science, an interest in theory; Artistic (A) = creative expression in art and writing, little need for structure; Social (S) = people interests, the helping professions, teaching, nursing, counseling; Enterprising (E) = likes leadership roles directed toward

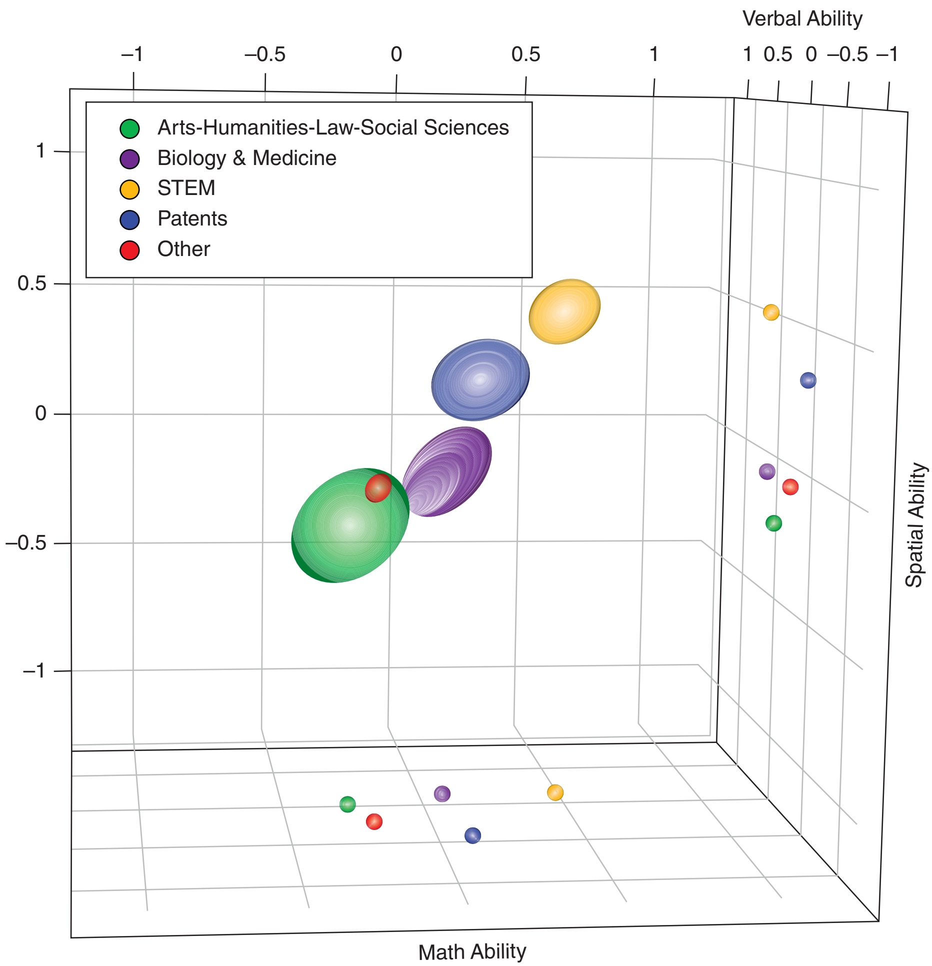

Figure 19.5 Three-dimensional confidence ellipsoids plotted for mathematical (*x*-axis), spatial (*y*-axis), and verbal (*z*-axis) reasoning ability for five creative accomplishment categories. Ellipsoids are scaled so that each semiprincipal axis is approximately equal in length to the standard error of the corresponding principal component. The ellipsoids are centered on the trivariate mean (centroid), and bivariate means are plotted on the bordering grids. Adapted from Kell, Lubinski, Benbow, and Steiger (2013).

economic objectives; and Conventional (C) = liking of well-structured environments and clear chains of command, such as office practices. Scores on themes closer together in the hexagonal space covary most strongly, and after its six components, the model is often referred to by the acronym “R-I-A-S-E-C.”

John Holland (1959, 1996) justifiably receives most of the credit for this model (Day & Rounds, 1998), although Guilford *et al.* (1954) developed a similar framework using large samples of military personnel. Although each theme contains multiple subcomponents, Holland’s hexagon, like the radex of cognitive abilities, represents a molar outline of the educational/occupational interest domain, but there are molecular strands of intellective and interest dimensions that add nuance to both these general models (for abilities, see Carroll, 1993; for interests, see Dawis, 1991; Savickas & Spokane, 1999). Additionally, at a broader level, there are also superordinal interests, such as *data versus ideas* (Prediger, 1982) and *people versus things* (Su, Rounds, & Armstrong, 2009), the latter manifesting arguably the largest sex difference on a continuous psychological dimension of human individuality.

Constellations of attributes

At the superordinate level of people versus things or data versus ideas, or at the more molecular RIASEC level, interests covary with mathematical, spatial, and verbal abilities in different ways (Ackerman, 1996; Ackerman & Heggestad, 1997; Schmidt, Lubinski, & Benbow, 1998). As a consequence, intense selection, when restricted to a specific ability, will eventuate in distinctive interest profiles across the three exceptional ability groups isolated and capture potential for differential development (Humphreys *et al.*, 1993; Webb, Lubinski, & Benbow, 2007) – satisfaction and satisfactoriness. Although correlations between abilities and interests are typically "only" in the .20–.30 range, when selection is extreme on different specific abilities, distinct profiles emerge, reflected in different "intellectual types" (Lubinski & Benbow, 2000, 2006). This shows how, at the extreme, ostensibly different kinds of intellectual types can arise, but that they do not stem from different qualities. Rather, these types constitute endpoints within a multivariate space of systematic sources of individual differences, because different specific abilities "pull" with them different constellations of nonintellectual personal attributes.

Covariation of intellective and affective attributes may partially explain why, when dealing with those who produce exceptional accomplishments (let alone true geniuses), some may be moved to consider such individuals qualitatively different from one another. The kinds of extraordinary achievements encountered when moving across contrasting disciplines (e.g., literature, technology) are so different that they only underscore the uniqueness of their creators. Might not Leo Tolstoy, author of *War and Peace*, have had a different "kind" of mind than Thomas Edison, inventor of the phonograph? And yet, when exceptional performances are subjected to critical analysis, it is possible that what will be uncovered are not unique qualities, but rather *more* of certain qualities (i.e., affective, cognitive) that lead to qualitative differences in knowledge content and different "types of eminence." Contrasting profiles of specific abilities and interests among those with great intellectual potential can eventuate in radically different achievements, just as contrasting physiques among the athletically gifted can portend success in different Olympic events (Tanner, 1965) and ostensibly indicate different "types of athletes."

If we assume that correlations between quantitative, spatial, and verbal reasoning abilities are all around .75, this leaves much room for profile variability. Indeed, appreciable variability is expected, especially when selection is stringent and exclusively restricted to one ability dimension. For instance, someone four standard deviations above the norm on verbal reasoning abilities (i.e., top 1 in 10,000) would be in possession of the specific cognitive ability for greatness in law, literature, or philosophy, among other verbal-linguistic disciplines. Yet, this individual might not be distinct from many faculty members at major universities on other specific abilities. The mean expectation for this person's quantitative and spatial reasoning abilities (with

$R_{VQ} = R_{VS} = .75$, and with V four standard deviations above the norm) is three standard deviations above the norm (i.e., $.75 \times 4 = 3$), or approximately the top 1 or 2 in 1,000. To be sure, being among the top 1 or 2 in a group of 1,000 is impressive, but it is not nearly as impressive as being the top 1 in 10,000 – and not so awfully rare at elite educational institutions. This amount of intellectual diversity is the expectation for anyone so verbally exceptional. It also would be the amount of diversity anticipated (under the same assumptions) for someone as exceptional in quantitative or spatial reasoning. Three groups of individuals, selected for their exceptionality in quantitative, spatial, or verbal reasoning, would appear quite distinct from one another – and in some important respects they would be. However, the very magnitude of their distinctiveness could overshadow their commonalities.

Might creators of exceptional intellectual products not be nearly so enigmatic as often thought? Can measures associated with major dimensions of cognitive abilities capture their distinctiveness quantitatively? Could these measures also explain how quantitative differences in individual differences profiles develop into qualitative differences in knowledge structures? Recall that specific abilities "pull" with them unique clusters of noncognitive personal attributes (Ackerman, 1996; Ackerman & Heggestad, 1997), oftentimes in opposite directions. In Schmidt *et al.*'s (1998) study of gifted adolescents, for example, spatial abilities covaried approximately .25 with realistic interests (working with things) and −.25 with social interests (working with people). If spatially talented students are selected using a cutting score of two standard deviations above the mean, the resulting sample would average half a standard deviation above the mean in interests in working with things ($2 \times .25 = .50$) and half a standard deviation below the mean in interests in working with people ($2 \times -.25 = -.50$). Collectively, these two patterns would cover a full standard deviation difference in interests for people versus things (see the RIASEC component in Figure 19.1).

These differences would be conspicuous enough to motivate categorical considerations. They would certainly generate stereotypic impressions of "different types" if compared with members of highly talented groups selected on verbal and spatial abilities, because both covary inversely with other interests. Consider the result if the cutting score had been four standard deviations above the mean, rather than two. Now, think of Edison, who held over 2,300 patents, covering inventions as diverse as electric lamps, waterproof paints, and cement kilns (Dyer & Martin, 1910; Israel, 1998). Compare him with Tolstoy, who produced 100 volumes of written work and learned Ancient Greek in three months (Bartlett, 2011). How many standard deviations above the norm might Edison have been on spatial ability and Tolstoy on verbal ability? How different might these two geniuses have also been on a variety of other personal attributes?

The preceding example strives to illustrate that selecting two groups at the extremes on any pair of the major markers of general intelligence (math/verbal, math/space, verbal/space) eventuates in multiple group differences on other major individual differences dimensions. Moreover, such group differences are often sufficiently pronounced to stimulate reasonable observers to consider discontinuities. Yet, as we have seen, these constellations could stem from continuous gradations within an underlying multivariate space of systematic sources of individual differences with no discrete boundaries. It could turn out that exceptional achievements are "simply" outcomes of optimal blends of extraordinary levels of normative cognitive and affective characteristics, which have encountered environments supportive of further and more focused development.

Despite their importance, however, cognitive ability (general and specific) and interests paint an incomplete portrait of the psychology of exceptionality, let alone genius. It takes more than cognitive capacity and mere enjoyment of writing to produce 100 volumes, and it takes more than enjoying inventing to hold over 2,000 patents. For an insight into this level of accomplishment, a final class of important psychological determinants is needed. This class of attributes reveals an important similarity across exceptional performers.

Conation

As parents of multiple children know, there are huge individual differences in the extent to which individuals embrace opportunities for positive development.[1] Seasoned faculty at top educational institutions have observed the same: Even among highly select graduate students, task commitment varies tremendously. Among the intellectual elite, individual differences in accomplishments stem from more than abilities and interests; conative determinants represent the final critical individual differences catalyst. Taken together, these conative attributes have been called many things, with vigor or zeal (Galton, 1869), will (Webb, 1915), and industriousness (Hull, 1928) being among their most common labels. Regardless of the title, these personal resources serve to mobilize abilities and interests, and partly explain individual differences in engagement with settings designed to foster learning, work, or the development of creative advances. Conative factors can be distinguished from abilities and preferences, and have more to do with individual differences in energy or psychological tempo than what people can or like to do. Indeed, scientific studies of expertise and world-class accomplishment consistently indicate the importance of indefatigable capacities for study and work. Although Ackerman (1996) has discussed *Typical Intellectual Engagement* (TIE) and Dawis and Lofquist (1984) have discussed *pace* and *endurance*, this is a supremely underappreciated class of individual differences that is worthy of much more attention and measurement applications when modeling individual differences in accomplishment.

In spite of this neglect in longitudinal modeling, in the field of talent development and expertise, the greatest consensus appears to be found on this topic of conation, rather than cognition or affect. Exceptional performers are deeply committed to what they do, and they accordingly devote a great deal of time to doing it! Regardless of the theorist (e.g., Anders Ericsson, Howard Gardner, Arthur Jensen, Dean Simonton, Harriet Zuckerman), all agree that this is a uniform characteristic of world-class performers functioning at the peak of their powers. In the words of Dean Simonton and E. O. Wilson, respectively:

> [M]aking it big [becoming a star] is a career. People who wish to do so must organize their whole lives around a single enterprise. They must be monomaniacs, even megalomaniacs, about their pursuits. They must start early, labor continuously, and never give up the cause. Success is not for the lazy, procrastinating, or mercurial. (Simonton, 1994, p. 181)

> I have been presumptuous enough to counsel new Ph.D.s in biology as follows: If you choose an academic career you will need 40 hours a week to perform teaching and administrative duties, another 20 hours on top of that to conduct respectable research, and still another 20 hours to accomplish really important research. This formula is not boot-camp rhetoric. (Wilson, 1998, pp. 55–56)

Figure 19.6 displays data from two extraordinary populations of individuals (Lubinski *et al.*, 2006). One group consists of a sample of young adolescents identified at age 12 as in the top 1 in 10,000 in mathematical or verbal reasoning ability and subsequently followed longitudinally for 20 years. Members of the second group were identified in their early twenties, as first- or second-year STEM graduate students enrolled in a top 15 U.S. university and subsequently tracked for 10 years. In their mid-thirties, subjects were asked, first, how much they would be *willing to work* in their "ideal job" and, second, how much they actually *do work*. The data are clear: There are huge individual differences associated with how much time people are willing to invest in work lives and career development. The STEM graduate students are particularly interesting, as in their mid-twenties, they were assessed on abilities, interests, and personality, and both sexes were found to be highly similar on these psychological dimensions (Lubinski *et al.*, 2001). But, over time, they markedly diverged in time allocation and life priorities (Ceci & Williams, 2011; Ferriman *et al.*, 2009).

Figure 19.6 reveals huge *noncognitive* individual differences among individuals with exceptional intellectual talent. One only needs to imagine the ticking of a tenure clock and the differences likely to accrue over a five-year interval between two faculty members working 45- versus 65-hr weeks (other things being equal). Making partner in a prestigious law firm is no different; nor is achieving genuine excellence in most intellectually demanding areas.

Emergence of Genius

We have discussed how geniuses with accomplishments in very different fields may appear to differ qualitatively from one another because of the effects of extreme selection on even a single attribute. Geniuses appear to be categorically different not only from one another, but, peering down from the heights of their accomplishments, also from the rest of mankind. The most extreme point in this line of reasoning is expressed by Hirsch (1931, p. 298): "The genius differs in *kind* from the species, man." Although Hirsch goes too far, the thoughts and emotions elicited by staring up at the ceiling of the Sistine Chapel, for example, may make his view at least momentarily understandable (Murray, 2003). Even if geniuses do constitute a characteristic "type," however, the type itself springs from the covariation of extreme levels of familiar attributes that differ on quantitative continua. Typically, developing human beings possess degrees of intelligence, passion, and commitment – but *only* in populations where all three attributes are present at high levels is there even the possibility that genius might emerge.

And *emerge* is exactly what genius seems to do. Some scientific treatments of genius (e.g., Eysenck, 1995; Simonton, 1994, 1999a) posit emergenesis (Lykken, 1982; Lykken, McGue, Tellegen, & Bouchard, 1992) as a promising mechanism for understanding why geniuses appear to constitute a "quantum leap" beyond the remainder

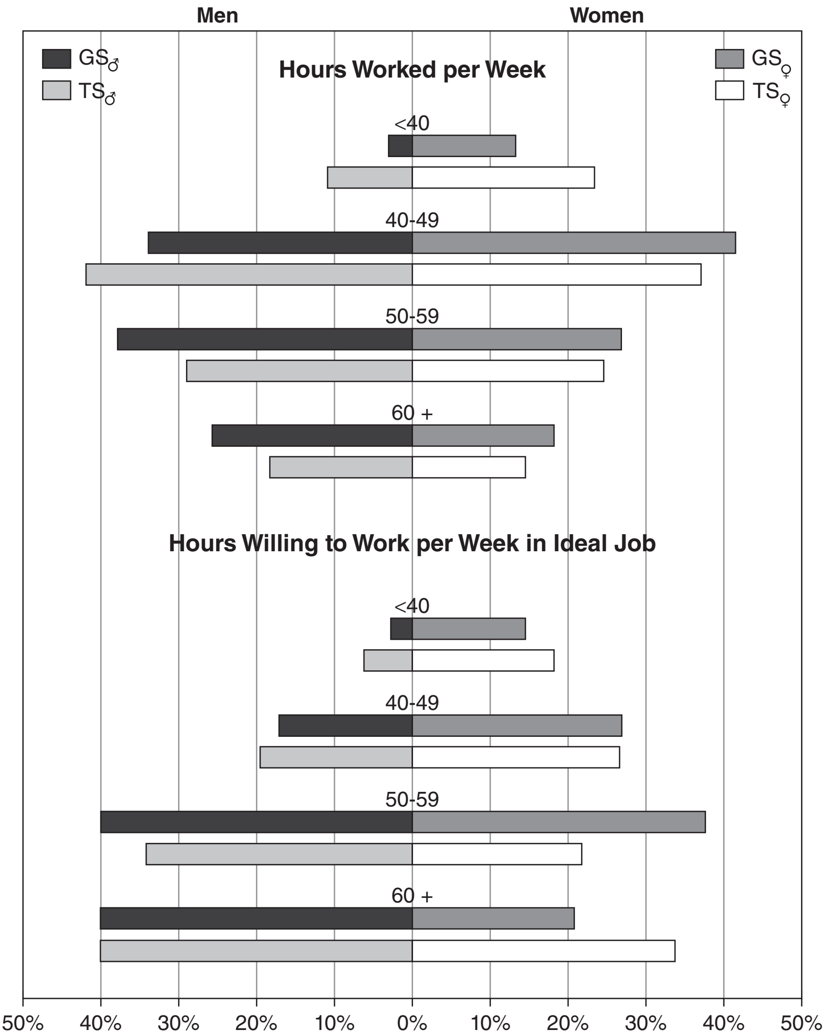

Figure 19.6 Hours worked per week (top) and hours willing to work per week in ideal job (bottom) for top STEM Graduate Students (GS) and Profoundly Gifted Talent Search (TS) participants now in their mid-thirties (from Lubinski *et al.*, 2006).

of humanity. Emergenesis stipulates that certain complex traits constitute an emergent property of highly specific configurations of more basic traits. If a single trait is absent *or* not present at a certain level, the emergent trait will not appear. Importantly, emergent traits are not revealed as "inherited," per se, inasmuch as individuals inherit levels on specific traits but rarely the entire set of mutual relations in the proper level and patterning necessary for an *emergent trait* to manifest itself. Conceiving of genius as an emergent trait may explain why it does not run in families (Lykken, 1982; Simonton, 1999a, 1999b) and why geniuses appear to constitute a category unto themselves. In *Hereditary Genius*, Sir Francis Galton approximated this conceptualization, and in the process eloquently expressed both its inherent rarity and the necessity for great achievement:

> Ability must be based on a triple footing, every leg of which has to be firmly planted. In order that a man should inherit ability in the concrete, he must inherit three qualities that are separate and independent of one another: he must inherit capacity, zeal, and vigour; for unless three, or, at the very least, two of them are combined, he cannot hope to make a figure in the world. The probability against inheriting a combination of three qualities not correlated together is necessarily in a triplicate proportion greater than it is against inheriting any one of them. (Galton, 1869, p. 75)

Emergenic models (e.g., Lykken *et al.*, 1992; Simonton, 1999b) are multiplicative, rather than additive, and in being so suggest that genius is indeed not the sum of its parts, but the product. We offer the following, highly simplified, example to illustrate this multiplicative mechanism and demonstrate why it is a compelling explanation for both the extreme rarity and typological appearance of genius. First, imagine that human beings vary from 1 to 10 on scales measuring ability, passion, and commitment – the three traits specified to be necessary for genius to manifest. Consider standings on each of the traits to be relatively independent of standings on the others. Next, take the product of an individual's three scores as an indicator of that person's "potential for genius" (after Simonton's, 1999b, "potential level of talent"). Let us set an overly generous product score as the cut for when "minor genius" (e.g., the likes of Sartre, when compared with Shakespeare; Murray, 2003) can begin to emerge: 500.

Now assume that the average full-time professional worker scores "3" on each of these traits, leading to a product score of merely 27. If we think of an intellectually gifted person as scoring "6" on the ability scale and 3 on the other two trait scales, it would yield only a product of 54. An intellectually gifted person who is similarly passionate and committed would score 216 – not even half-way to the threshold for the emergence of minor genius. Indeed, in order to even barely pass the given cut score, an individual would have to score "8" on all three abilities; a decline to 7.5 on a single ability would disqualify a person as having the potential for low-level genius. If we set a cut of 900 as indicating potential for a person to become a "true giant" (e.g., Darwin, Pasteur), an individual could only afford to score "9" on a single measure – the other two traits would have to be at ceiling for even the possibility of a "major genius" to appear.

This, admittedly crude, emergenic model merely illustrates what, in combination with extreme selection criteria, is a useful perspective for considering how different "kinds of genius" can arise from a combination of basic traits. Demystifying genius and focusing on its familiar roots is important for the purposes of talent identification and development, as doing so suggests that identifying populations at promise for achieving exceptional feats – even if not always genius-level ones – is a legitimate possibility. In fact, the achievements of the following publicly identified SMPY participants push this idea from a possibility to harboring verisimilitude (Muratori *et al.*, 2006).

Terence ("Terry") Tao is professor of mathematics at the University of California, Los Angeles (UCLA). He was promoted to the rank of full professor at the age of 24 – four years after joining the faculty at UCLA. His many accomplishments include winning the Fields Medal (often described as the "Nobel Prize of mathematics") in 2006, receiving a MacArthur Fellowship in 2007, and being elected fellow of the American Academy of Arts and Sciences (AAAS) in 2009. Susan Athey is professor of economics at the Stanford Graduate School of Business. Previously, she held faculty positions at Harvard University and the Massachusetts Institute of Technology. She is the first woman ever to win the John Bates Clark Medal (in 2007), which is awarded "to that American economist under the age of 40 who is judged to have made the most significant contribution to economic thought and knowledge" (American Economic Association, 2013). Among her many other distinctions, Athey was elected fellow of the AAAS in 2008 and the National Academy of Sciences in 2012. Finally, Colin Camerer is the Robert Kirby Professor of behavioral finance and economics at the California Institute of Technology and one of the founders of the field of neuroeconomics. Previously, he held faculty positions at Northwestern University, the University of Pennsylvania, and the University of Chicago. His many honors include serving as president of the Economic Science Association from 2001 to 2003, being elected to the AAAS in 2003, and serving as president of the Society for Neuroeconomics from 2005 to 2006. The talents of all three of these exceptionally high-achieving individuals were identified early on and constitute the fabric from which genius can emerge.[2]

Concluding Thoughts

Julian C. Stanley, SMPY's founder, questioned whether genius could be studied scientifically, and perhaps he was right. We have described how high standings on cognitive abilities, when accompanied by intense passion and dedication, can eventuate in astounding accomplishments; the exceptional achievements of many SMPY participants are proof of this. But we only examined the broad dimensions of cognitive abilities and interests to provide our framework, and not the more molecular strands of cognitive abilities and interest that give nuance to the nature and organization of human potentialities and preferences (cf. Carroll, 1993; Dawis, 1991, 1992). We have also described a mechanism – emergenesis – that plausibly accounts for how these familiar psychological elements can combine with conative determinants, at extreme levels, to propel rare human accomplishments. And yet, our description still fails to capture the totality of genius. Take, for instance, the following account of Mozart's capacity to improvise and "compose on the spot":

> Even in the 6th year of his age he would play the most difficult pieces for the pianoforte, of his own invention. He skimmed the octave which his short little fingers could not span, at fascinating speed and with wonderful accuracy. One had only to give him the first subject which came to mind for a fugue or an invention: he would develop it with strange variations and constantly changing passages as long as one wished; he would improvise fugally on a subject for hours, and this fantasia-playing was his greatest passion. (Deutsch, 1965, p. 512)

Such talent cannot be adequately "explained" by ability, passion, devotion, and opportunity; something elusive remains. Geniuses of the highest rank have been called "magicians," whose mental processes are mysterious, even after their products have been understood (cf. Jensen, 1996, p. 396). Because Newton recognized the connection between the moon's motion and falling bodies on earth, McDougall (1923) described the discovery of gravity as an extreme instance of Spearman's (1927) "eduction of relations," a central aspect of *g*, but identifying this feat with a psychological label does not explain it.[3] Nomothetic inquiry can take us only so far and up to a point, after which aspects of idiographic uniqueness remain (Lubinski, 1996), as it most assuredly does for genius.

Nevertheless, this model for conceptualizing the chief psychological aspects of genius does not minimize the role unique configurations of nomothetic traits play in the scientific study of exceptionality, or that there are phenomenological experiences inaccessible to intersubjective confirmation (Lubinski & Thompson, 1993, pp. 667–668, footnote 2, p. 674). Since Spearman's (1904) discovery of general intelligence, a steady stream of systematic scientific knowledge has accrued in the psychological study of human individuality. We have learned that the intellect is organized hierarchically, that interests are multidimensional and covary only slightly with specific abilities, and that individual differences are huge in terms of investing in personal development. When these aspects of human psychological diversity are combined with commensurate attention devoted to opportunities for learning, work, and personal growth, a framework for understanding extraordinary human development begins to take shape, which we believe sheds scientific light on manifestation of genius.

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Notes

1 Space limitations preclude a detailed discussion of how educational interventions can enhance the likelihood of creative accomplishment among intellectually precocious youth. Interested readers are referred to Benbow and Stanley (1996), Bleske-Rechek, Lubinski, and Benbow (2004), Park, Lubinski, and Benbow (2013), Stanley (2000), and Wai, Lubinski, Benbow, and Steiger (2010).

2 Terry, Susan, and Colin have given SMPY permission to mention them in our scholarship, and we thank them here for helping us illustrate the point we are trying to make.

3 Spearman (1927; Spearman & Wynn Jones, 1950) described *g* in terms of three noegenetic laws: eduction of relations, eduction of correlates, and apprehension of experience. By "noegenesis," Spearman meant the production of new knowledge (Jensen, 1998), suggesting he believed *g* and creativity were inextricably linked. McDougall (1923) used the term "apperceptive synthesis" to describe the phenomenon Spearman later named eduction of relations.

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