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Spatial Ability: A Neglected Talent in Educational and Occupational Settings

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For over 60 years, longitudinal research on tens of thousands of high ability and intellectually precocious youth has consistently revealed the importance of spatial ability for hands-on creative accomplishments and the development of expertise in science, technology, engineering, and mathematical (STEM) disciplines. Yet, individual differences in spatial ability are seldom assessed for educational counseling and selection. Students especially talented in spatial visualization relative to their status on mathematical and verbal reasoning are particularly likely to be underserved by our educational institutions. Evidence for the importance of assessing spatial ability is reviewed and ways to utilize information about individual differences in this attribute in learning and work settings are offered. The literature reviewed stresses the importance of spatial ability in real-world settings and constitutes a rare instance in the social sciences where more research is not needed. What is needed is the incorporation of spatial ability into talent identification procedures and research on curriculum development and training, along with other cognitive abilities harboring differential—and incremental—validity for socially valued outcomes beyond IQ (or, *g*, general intelligence).

Keywords: cognitive abilities, creativity, gifted, human capital, innovation, intellectual abilities, spatial ability, spatial visualization, STEM, talent development

Spatial ability is implicated in scientific achievement—Einstein, Faraday, Maxwell, and Tesla indicated that imagistic processes played a critical role in their creative breakthroughs (Lohman, 1994a; Shepard, 1978; Uttal et al., 2013). Innovation in science, technology, engineering, and mathematical (STEM) domains underlies national prosperity and is crucial to remaining competitive in the international economy (Friedman, 2007; Friedman & Mandelbaum, 2011; Rindermann & Thompson, 2011). For decades, large-scale longitudinal research has consistently revealed that spatial ability plays a unique role in accomplishment in STEM fields (Super & Bachrach, 1957; Wai, Lubinski, & Benbow, 2009). Through its association with STEM innovation (Kell, Lubinski, Benbow, & Steiger, 2013), spatial ability is perhaps more important now than ever before. Appreciating the psychological significance of spatial ability is also critical for understanding why some students gravitate toward STEM disciplines—and why other students avoid them.

In this article, we underscore the importance of spatial ability by placing it in a broader context: the consensus on a hierarchical organization of cognitive abilities. Spatial ability, and the contrasting configurations it forms with individual differences in general, mathematical, and verbal reasoning abilities have important implications for human development. This knowledge benefits educators, counselors, and psychologists in creating opportunities to facilitate positive development among students and, ultimately, among lifelong learners in the world of work. This includes those at the forefront of making the kinds of generative, creative products (e.g., scientific advances, technology patents) necessary for maintaining and advancing modern societies.

DEFINING AND MEASURING SPATIAL ABILITY

Spatial ability is the mental capacity for "manipulating visual patterns, as indicated by level of difficulty and complexity in visual stimulus material that can be handled successfully" (Carroll, 1993, p. 362). Individuals with high spatial aptitude are skilled in carrying out diverse mental operations on complex figures, including rotation, reflection, folding/unfolding, and combination with other stimuli (Lohman, 1988, 1989; Pellegrino, Alderton, & Shute, 1984; Smith, 1964). Accuracy, rather than speed, is emphasized

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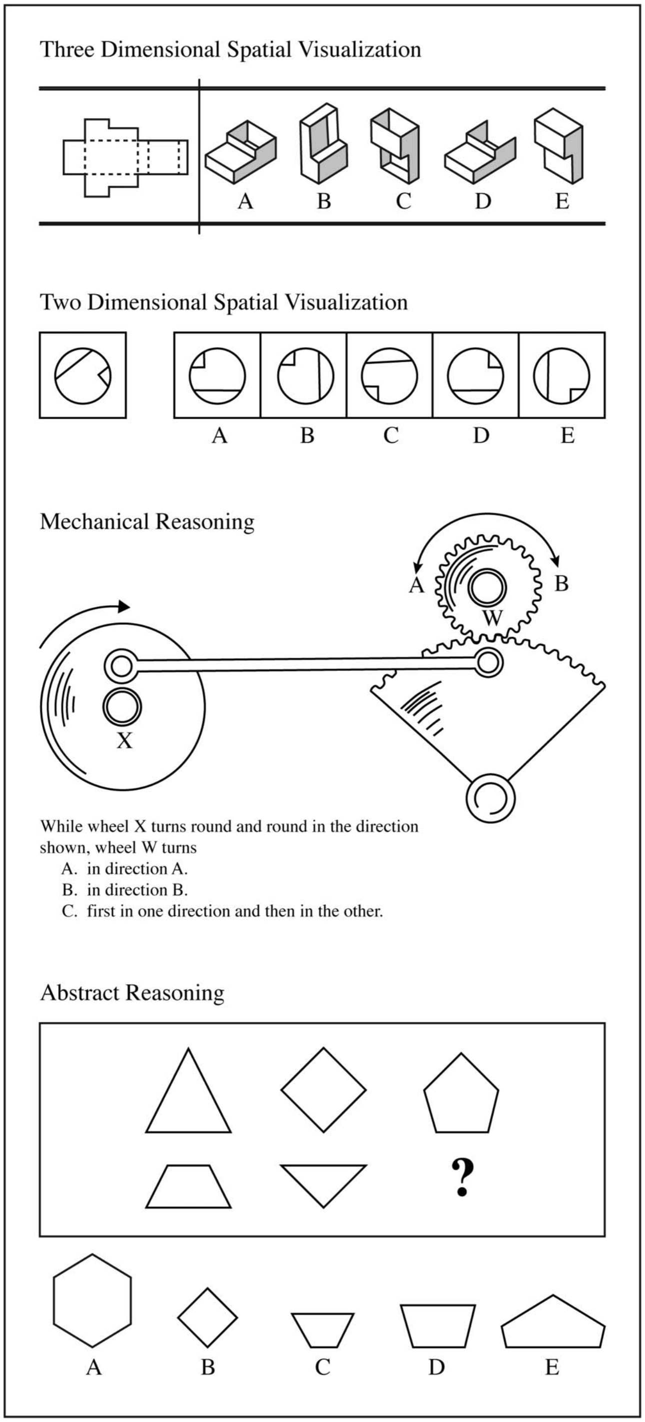
when solving spatial problems. However, individuals who do poorly on spatial–visualization tests tend to be inaccurate *and* slow (Pellegrino et al., 1984), relative to those who are more facile in spatial visualization. Fundamentally, spatial ability measures seem to place demands on the quality of individuals' mental representations of target figures, including their complexity; if test-takers cannot generate high-quality images, they will also not be able to mentally transform them accurately (Lohman, 1988).

Nearly all forms of battery-type cognitive tests include items that measure spatial ability (Hunt, 2011), but inventories have also been developed that assess spatial visualization exclusively. Some common items that appear in tests of spatial ability are depicted in Figure 1.

Carroll (1993) and Eliot and Smith (1983) reviewed the major types of spatial tests, which include assembly (combining pieces in two or three dimensions to form a specified shape), blocks (counting the number of blocks in a pile), rotation (deciding which figure is the same as a target stimulus when rotated), surface development (matching a three-dimensional object to a given two-dimensional drawing), and mechanical movement (making judgments about the operations of mechanical stimuli).

HISTORY OF SPATIAL ABILITY ASSESSMENT

Despite the contemporary neglect of spatial ability in education, counseling, and industrial psychology, the history of spatial ability is deeply embedded in the mental testing tradition. Assessment of mental competence via tasks now recognized as spatial reasoning measures dates back to the 19th century (Itard, 1801/1962). The Binet-Simon (Binet & Simon, 1905) and Stanford-Binet (Terman, 1916), two of the earliest versions of modern mental tests, included spatial ability items. Spatial–visualization has long been associated with hands-on tasks, such as facility in operating machinery (Carroll, 1993; Vernon, 1961). By the 1920s, scores on spatial tests were being used as a means of awarding scholarships in trade schools (Smith, 1964) and for personnel selection in nonprofessional occupations (Viteles, 1932). Hugo Münsterberg (1913), industrial psychology's founder, developed a visual and mechanical simulation task to select trolley car drivers, and Donald G. Paterson, a pioneer of vocational counseling and industrial psychology (Erdheim, Zickar, & Yankelevich, 2007), developed the Minnesota Paper Form Board (Paterson, Elliott, Anderson, & Toops, 1930), a spatial ability assessment still in use today (Humphreys & Lubinski, 1996).



Three Dimensional Spatial Visualization

Two Dimensional Spatial Visualization

Mechanical Reasoning

While wheel X turns round and round in the direction shown, wheel W turns
A. in direction A.
B. in direction B.
C. first in one direction and then in the other.

Abstract Reasoning

FIGURE 1 Depictions of common items found in tests of spatial visualization. Adapted from "Spatial Ability for STEM Domains: Aligning over Fifty Years of Cumulative Psychological Knowledge Solidifies its Importance," by J. Wai, D. Lubinski, and C. P. Benbow, *Journal of Educational Psychology, 101* (2009, p. 822).

Spatial ability assessments have made a major impact in the military. To evaluate the mental competence of conscripts in World War I, the Army Alpha and Beta tests were devised. The Army Alpha test was administered to literate soldiers and contained relatively few spatial items. The Army Beta test featured relatively more spatial items and was administered to illiterate or non-English-speaking soldiers, for whom verbal items were presumed to be less valid (Humphreys & Lubinski, 1996). About 1,700,000 men took one of these tests (Ackerman & Heggestad, 1997). Also in use during World War I was the more purely spatially oriented Mechanical Assembly Test (MAT; Stenquist, 1922), which required test-takers to assemble pieces of objects such as locks and bicycle bells. Foreshadowing current attitudes (i.e., privileging verbal/quantitative over spatial ability), the MAT was dropped from assessment practices when it was found that scores on it did not strongly correlate with scores on the verbally oriented Army Alpha test, despite the fact that performance on the MAT was related to soldiers' quality of work (Smith, 1964).

The Alpha and Beta tests were replaced by the Army General Classification Test in World War II, which included a spatial–visualization component. A special qualifying test focused specifically on spatial ability was also developed for pilot candidates (Humphreys & Lubinski, 1996). The postwar replacement for the Army General Classification Test, the Armed Forces Qualifying Test, also featured spatial items for part of its history. The current test battery used in the military, the Armed Services Vocational Aptitude Battery, does not include spatial–visualization items. The Armed Services Vocational Aptitude Battery does, however, feature several knowledge-based subtests (e.g., Mechanical Assembly, Object Assembly) used to determine whether recruits are eligible for special training courses (Hunt, 2011). These tests could serve as surrogates for spatial measures, however, as Carroll (1993) suggested, inasmuch as spatial aptitude facilitates acquisition of knowledge about mechanical operations.

SPATIAL ABILITY IN CONTEXT

Spatial, mathematical, and verbal reasoning constitute the chief specific abilities with implications for different choices and performance after those choices in learning and work settings (Corno et al., 2002; Dawis, 1992, 2001; Gottfredson, 2003; Lubinski, 2004). The content of tests that measure these specific abilities assess different modalities of thought: reasoning with numbers, words, and figures or shapes. Yet, despite this disparate content and focus, contrasting specific ability tests are all positively correlated. What these tests share is an underlying general ability dimension and a common property of intellectual thought.

This general dimension, identified over 100 years ago (Spearman, 1904) and corroborated by a massive quantity of subsequent research (Carroll, 1993; Jensen, 1998), is *general mental ability*, the *general factor*, or simply *g* (Gottfredson, 1997). General mental ability represents the complexity/sophistication of a person's intellectual repertoire (Lubinski & Dawis, 1992; Snow & Lohman, 1989). The more complex a test is, regardless of its content (e.g., mathematical, verbal, spatial), the better a measure of *g* it is (Jensen, 1998). Further, because *g* underlies all cognitive reasoning processes, any test that assesses a specific ability is also, to some extent, a measure of *g* (Lubinski, 2004).

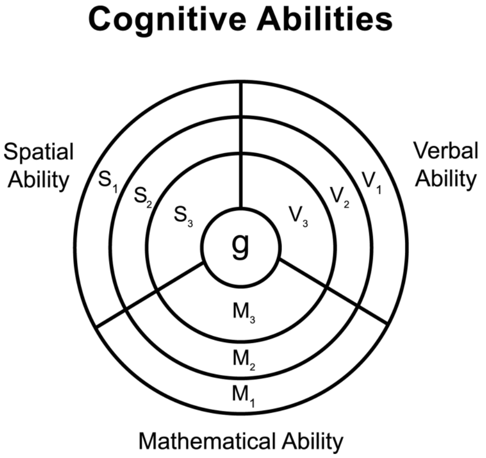


FIGURE 2 The radex of cognitive abilities organizes cognitive abilities around mathematical, spatial, and verbal content domains, with the higher order construct of *g*, or general intelligence, at the center representing the communality shared by these specific abilities. Adapted from Wai et al. (2009, p. 821).

This conceptualization of cognitive abilities, and the tests that measure them, can be organized hierarchically (Carroll, 1993). A graphic representation of this cognitive hierarchy, the radex (Guttman, 1954), is depicted in Figure 2. The radex illustrates that scores on ability tests can covary as a function of their content or complexity (Lubinski & Dawis, 1992; Snow & Lohman, 1989). Tests can be scaled in this space as a function of 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 this space. Variability in test *complexity* is scaled from the center of the radex (*g*) out and, along lines emanating from the origin, complexity decreases but test content remains the same. Variability in test *content* is scaled around the circular bands with equal distance from the center of the radex, and moving around these bands test content changes from spatial/mechanical to verbal/linguistic to quantitative/numerical but test complexity remains constant; thus, 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 the radex space (Lubinski & Dawis, 1992; Snow & Lohman, 1989; Wai et al., 2009), this model is helpful in effectively organizing the many different kinds of specific ability tests currently available, because to the extent that a test's content and complexity are known, it may be located within this space.

Intertest correlations of specific abilities are never perfect, but because all cognitive assessments share a common general ability component it is unlikely, for example, that a person who scores extremely high on a test of spatial visualization will score extremely low on a test of quantitative ability or vice versa. That specific ability assessments are not perfectly correlated, however, leaves substantial room for intra-individual variation in intellectual profiles. Students are often stronger on one cognitive ability, relative to another, and this is important information inasmuch as different strengths and relative weaknesses reflect different potential for development. Gifted students, for example, are more likely than typical students to have uneven profiles when psychological assessments with appropriate ceilings are conducted (Achter, Benbow, & Lubinski, 1997; Achter, Lubinski, & Benbow, 1996; Kell, Lubinski, & Benbow, 2013; Lubinski, Webb, Morelock, & Benbow, 2001). Especially germane for the purposes of this article are the divergent developmental trajectories that marked discrepancies between spatial and verbal ability reflect (Humphreys, Lubinski, & Yao, 1993; Kell, Lubinski, & Benbow, 2013; Wai et al., 2009). Longitudinal data on the differential outcomes that contrasting ability patterns reflect are reported on next.

MAJOR RESEARCH FINDINGS

At the time of Sputnik's launch, a National Science Foundation blue ribbon committee was charged with reviewing and summarizing the scientific research on the psychological characteristics of young adolescents who ultimately go on to become STEM professionals (Super & Bachrach, 1957). They concluded that among young adolescents, high levels of mathematical and spatial reasoning combined with scientific interests and values portend the development of expertise, preference for, and persistence in STEM disciplines. The authors also suggested that researchers begin to assess these and other individual differences among students and study adolescent populations longitudinally for ways to identify young students with potential for STEM and, ultimately, to uncover ways to facilitate their development. Subsequent longitudinal research has done so (e.g., Bleske-Rechek, Lubinski, & Benbow, 2004; Park, Lubinski, & Benbow, 2013; Wai, Lubinski, Benbow, & Steiger, 2010), and Super and Bachrach's (1957) conclusions about the personal attributes indicative of promise in STEM have been supported by modern findings (Lubinski, 2010a; Lubinski & Benbow, 2006; Wai et al., 2009).

The results of five major investigations carried out over the past 20 years are reviewed next, and their consistency leaves little doubt as to the importance of spatial visualization in educational, occupational, and creative settings. Two of these studies drew on data from Project Talent (Flanagan et al., 1962), which consists of a stratified random sample of 400,000 students sampled from over 900 high schools nationwide. Students were comprehensively assessed (e.g., abilities, biographical information, interests, personality traits) in 1960 and follow-up data were collected 1, 5, and 11 years after they graduated from high school (Wise, McLaughlin, & Steel, 1979). The three other studies used data from the Study of Mathematically Precocious Youth (SMPY; Lubinski & Benbow, 2006). SMPY is a longitudinal study comprised of five cohorts of over 5,000 high-ability individuals. Cohorts were identified at different time points beginning in the 1970s. The majority of participants were identified during young adolescence through talent searches. Talent searches provide young adolescents who score in the top 3% on in-school achievement tests the opportunity to take college entrance exams, like the SAT, while they are in the seventh grade. Those scoring in the top 1% on SAT-M or SAT-V are given opportunities to attend summer residential programs for talented youth, where they experience learning opportunities commensurate with their intellectual readiness (Benbow & Stanley, 1996; Colangelo, Assouline, & Gross, 2004).

Five Studies

Among other things, Humphreys et al. (1993) used Project Talent subjects to examine the educational and occupational outcomes of several thousand students in Grades 9–12 in the top 20% on a math–verbal composite (which mirrored the SAT) and compared their outcomes to students in the top 20% on a math–space composite (developed for experimental purposes). Students scoring in the top 20% on both of these composites were also analyzed in this study, but here we will focus on those students who scored in the top 20% on one of these composites but not the other. Students scoring in the top 20% on math–space (but not math–verbal) were more attracted to undergraduate majors in engineering, mathematics, and computer science. A similar gravitation toward STEM-related majors occurred at the graduate level. For occupations outside of STEM, the math–space group was more likely to be found in vocational trades (e.g., artisan, electrician, and plumber). These findings were contrasted with the developmental trajectories of students scoring in the top 20% on math–verbal composite (but not the math–space composite); this group was more likely to favor the humanities and social sciences (outside of professional careers, clerical or office support staff positions were more likely to be favored by this group). The authors hypothesized that for selecting engineering students (and a variety of STEM professionals), a math–space composite is likely to harbor more validity than the traditional SAT (or the conventional math–verbal composite). We return to this idea in a later section.

Shea, Lubinski, and Benbow (2001) studied the educational and occupational outcomes of 563 intellectually gifted adolescents identified by SMPY in the late 1970s. Participants scored within the top 0.5% for their age group when administered the SAT by age 13. At the time of their identification, their spatial ability was also measured by a Differential Aptitude Test composite (viz. Space Relations + Mechanical Reasoning). Subsequently, educational and occupational criterion data were gathered 5, 10,

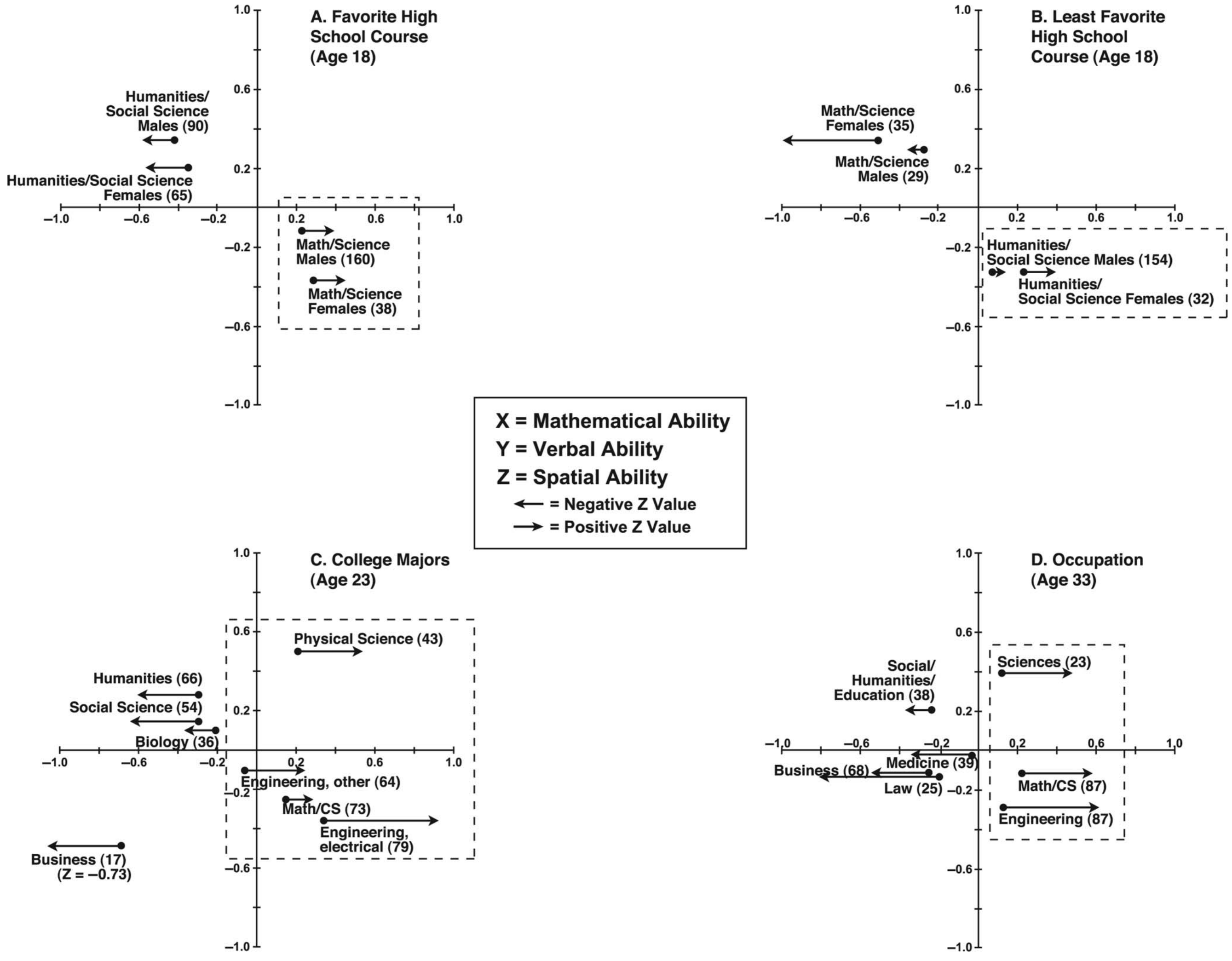


FIGURE 3 Shown are trivariate ($X/Y/Z$ = mathematical/verbal/spatial) means for (A) favorite and (B) least favorite high-school course at age 18, (C) college majors at age 23, and (D) occupation at age 33. Mathematical, verbal, and spatial ability are on the *x*-, *y*-, and *z*-axes, respectively (arrows to the right indicate a positive *z* value; arrows to the left indicate a negative *z* value). Panels A and B are standardized within sex; panels C and D are standardized across sexes. Sample sizes are found in parentheses. CS = computer science. Adapted from Wai et al. (2009, p. 820).

and 20 years later, and the relationship between their age-13 ability assessments and these outcomes are presented in Figure 3. Participants whose cognitive profiles favored spatial over verbal ability tended to prefer math/science courses in high school, earn undergraduate and graduate degrees in STEM, and pursue careers in STEM fields (Figure 3); those with the opposite ability pattern (i.e., verbal > spatial) tended to prefer the humanities and social sciences. Discriminant function analyses indicated that spatial ability added incremental validity to SAT-M and SAT-V in predicting these outcomes.

Webb, Lubinski, and Benbow (2007) drew on data from 1,060 SMPY participants identified in the mid-1990s. They represented the top 3% in ability and were also administered spatial ability tests as well as comprehensive educational–occupational preference questionnaires. Five years after their identification, an after-high-school follow-up gathered data on participants' favorite and least favorite high-school courses, hobbies, undergraduate major, and intended occupation. Across these criteria, spatial ability accounted for an additional 3% of the variance in predicting these outcomes beyond both SAT measures and two comprehensive educational–vocational preference questionnaires.

Wai et al. (2009) analyzed data from over 345,000 Project Talent participants to replicate and extend the findings reported by Shea et al. (2001). Once more, individuals stronger in spatial ability than verbal ability attained terminal degrees and pursued occupations in STEM areas, whereas individuals with the opposite intellectual pattern were more likely to choose learning environments and careers focusing on education, the humanities, and social sciences (see Figure 4). Due to the large sample sizes afforded by Project Talent's database, results of this investigation also allowed for a fine-grained examination of the

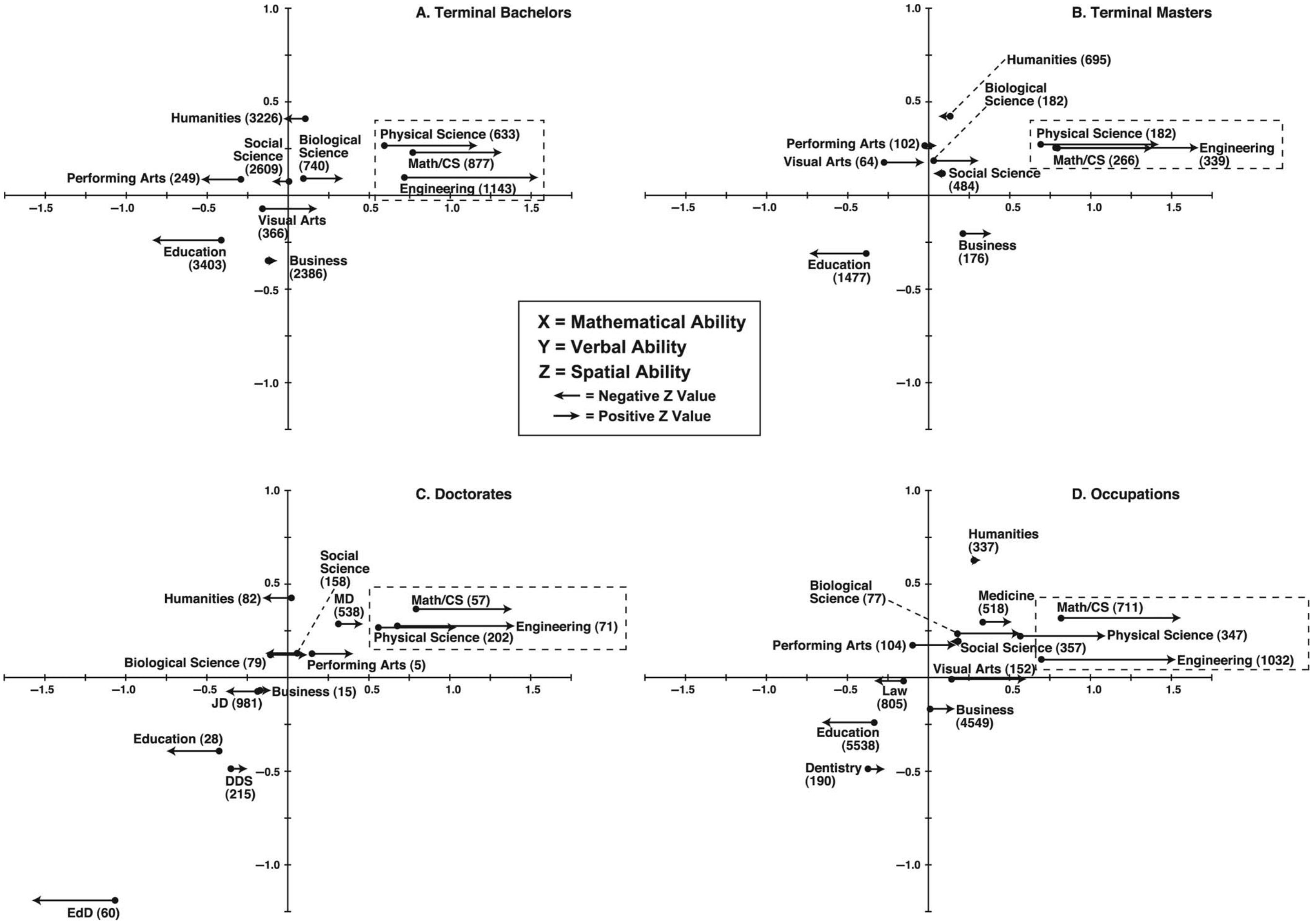


FIGURE 4 Trivariate means for (A) bachelors, (B) masters, (C) doctorates, and (D) occupations of those individuals whose data were included in panels A, B, and C. Panels A through D are standardized across sexes. Mathematical ability is on the *x*-axis, and verbal ability is on the *y*-axis; an arrow from each group mean indicates either positive (to the right) or negative (to the left) spatial ability. Breakdowns by sex are reported in Wai et al. (2009, Appendix A). The standard error of the mean for $n = 500$ was 0.04 and for $n = 1{,}000$ was 0.03. Data are from Project Talent. Sample sizes are found in parentheses. CS = computer science. Adapted from Wai et al. (2009, p. 824).

intellectual profiles of holders of advanced degrees in nine disciplines (see Figure 5).

Figure 5 displays cognitive ability portraits for three groups of terminal degree-holders: bachelors, masters, and doctorates. Three STEM disciplines and six other fields ranging from education to biology were analyzed to determine the ability level and pattern characteristic of each discipline. Consistently, higher ability levels were associated with more advanced degrees (as revealed on the *y*-axis). STEM degree-holders differed from non-STEM degree-holders in two important ways (Lubinski, 2010a). First, STEM degree-holders scored higher on *g* than degree-holders in other disciplines (as revealed on the *x*-axis). Second, as revealed on the *y*-axis, for all STEM areas and all three terminal degrees, spatial scores exceeded verbal scores, whereas the opposite pattern was consistently found in the other fields. A spatial ability > verbal ability pattern appears to be a salient psychological characteristic of individuals who select educational and career options in STEM, whereas the opposite pattern of spatial ability < verbal ability is characteristic of individuals who develop their talents in other disciplines. These precursors are intellectual configurations readily identifiable in junior high school.

Kell, Lubinski, Benbow, and Steiger (2013) extended the findings of the previous four studies to encompass the generation of new knowledge, supporting the hypothesis that spatial ability plays a unique role in the development of creative products in science and technology (e.g., Gardner, 1983; Shepard, 1978). Kell, Lubinski, Benbow, and Steiger (2013) conducted a 35-year longitudinal follow-up of the 563 participants reported on by Shea et al. (2001), when subjects were approximately 48 years old. Using the same three ability assessments utilized by Shea et al. (2001), namely, spatial, mathematical, and verbal, they predicted whether participants held four different kinds of creative products; the four creative outcomes consisted of (with sample sizes for these outcomes in parentheses) patents (33) or refereed articles published in the arts/humanities/law/social

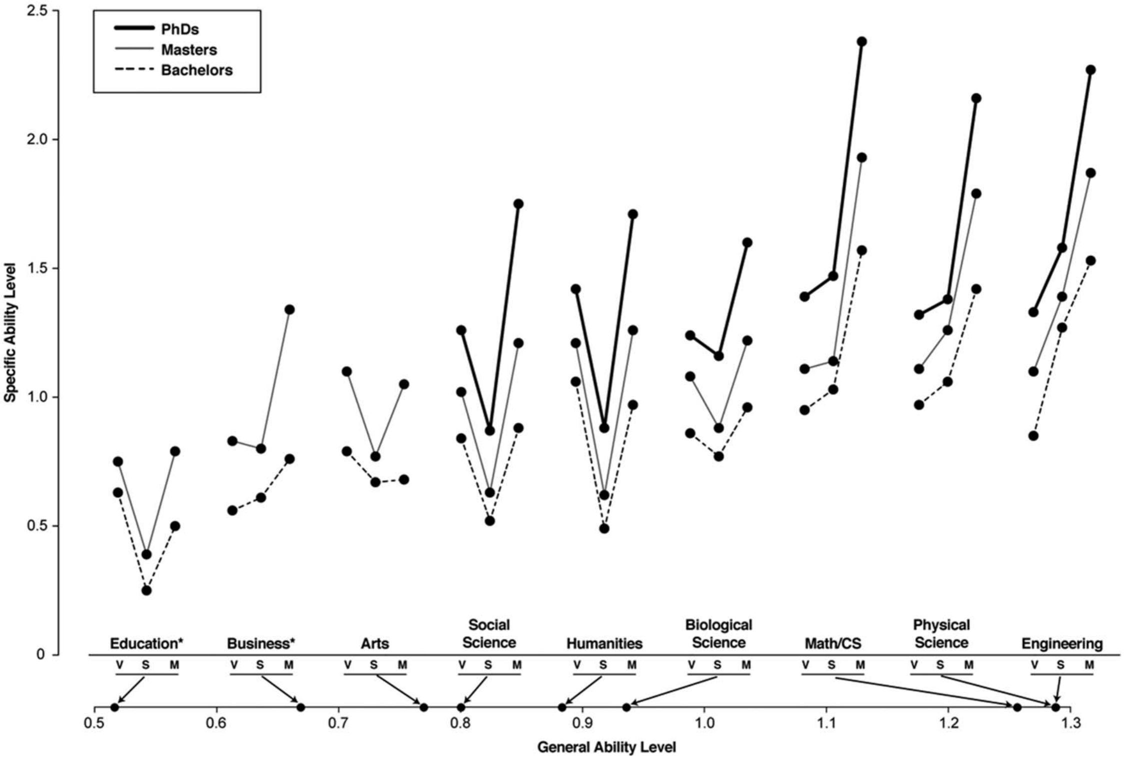


FIGURE 5 Average *z* scores of participants on verbal, spatial, and mathematical ability for terminal bachelor's degrees, terminal master's degrees, and doctoral degrees are plotted by field. The groups are plotted in rank order of their normative standing on *g* (verbal [V] + spatial [S] + mathematical [M]) along the *x*-axis, and the line with the arrows from each field pointing to it indicates on the continuous scale where they are 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). Adapted from "Neglected Aspects and Truncated Appraisals in Vocational Counseling: Interpreting the Interest–Efficacy Association From a Broader Perspective," by D. Lubinski, *Journal of Counseling Psychology, 57* (2010a, p. 232).

sciences (27), biology/medicine (35), or STEM (65). Using a two-step discriminant function analysis, the SAT-M and SAT-V accounted for 10.5% ($p < .01$) of the variation between these four groups, and when spatial ability was added an additional 7.5% ($p < .01$) of their variance was accounted for (18% total). To our knowledge, this is the first report that documents that spatial ability not only contributes added information to mathematical and verbal reasoning measures with respect to assimilating and utilizing knowledge in school and work settings, but it also contributes to the generation of new knowledge or creative expression.

The five studies reviewed here indicate that quantitative, verbal, and spatial ability play important causal roles in the complex of operative determinants for assimilating, utilizing, and generating knowledge; all three cognitive abilities are needed to capture the multidimensionality of human intelligence. Even when all three abilities are assessed, however, the measures used seldom have sufficient ceilings needed to capture exceptional development and fail to represent human ability in profound ranges. For years, we have known that individual differences within the top 1% of mathematical and verbal reasoning abilities, assessed by age 13, reflect differential potential for genuine manifestations of creativity in the humanities and STEM (Park, Lubinski, & Benbow, 2007). Even when advanced educational degrees and prestige of the university's awarding degrees are controlled for (Park, Lubinski, & Benbow, 2008), an ability threshold is not observed. Malcolm Gladwell (2008) notwithstanding, and though other things clearly matter (Lubinski & Benbow, 2000, 2006), more ability is clearly better.

SELECTION PROCEDURES AND THE UNDERUSE OF SPATIAL ABILITY

Perhaps because most historical evidence for the validity of spatial ability has been gathered in areas that emphasize manual operations (e.g., military, trade vocations) it has become stereotyped as unsuitable for people aspiring to professional careers (Humphreys & Lubinski, 1996).

A major factor in college admissions is the SAT, which features measures of quantitative and verbal reasoning (Frey & Detterman, 2004)—but absent is a test of spatial aptitude. Consequently, the aforementioned patterns of the three primary cognitive abilities are not assessed or studied for college admissions.

Despite the omission of spatial ability, the SAT, like the GRE, LSAT, and MCAT, is an effective predictor of grades (Camara & Echternacht, 2000; Kuncel & Hezlett, 2007; Sackett, Kuncel, Arneson, Cooper, & Waters, 2009). This, however, may be because current educational curricula are generally geared toward verbal and mathematical competence and place relatively slight demands on capabilities in spatial visualization (Lohman, 1988, 1994b). If a more substantial portion of educational criteria consisted of grades from hands-on courses and projects (e.g., created products in architectural studios, robotics, or science laboratories), it is likely that spatial ability measures would contribute added value or incremental validity to conventional assessments (Humphreys et al., 1993; Kell, Lubinski, Benbow, & Steiger, 2013; Shea et al., 2001). Indeed, scores on spatial tests have been shown to be predictive of retention and performance among dental, engineering, and geology students (Hambrick et al., 2012; Hegarty, Keehner, Khooshabeh, & Montello, 2009; Sorby & Baartmans, 2000).

In addition, with the exception of vocational trades and a few other occupations (e.g., pilot; Hunt, 2011), spatial ability is generally neglected in industry. As in educational settings, part of the reason for this may, ironically, be due to how successful general ability measures are for predicting performance. An overwhelming amount of evidence indicates that tests of general intellectual ability (*g*) are among the best predictors of job performance across nearly all jobs (Schmidt & Hunter, 1998). Specific abilities, such as spatial aptitude, do not add incremental validity in forecasting job performance once general ability is accounted for (Schmidt & Hunter, 1992). But again, just as there are other important educational criteria beyond how traditional grades in education are assessed, there are other important criteria in the world of work beyond the prediction of job performance (Cronbach, 1990; Dawis, 1996; Desmarais & Sackett, 1993), in particular, how niches for learning and work are chosen or self-selected among students and workers pursuing specific college majors and occupations, respectively, and whether commitment is likely to be maintained (persistence) once choices are made (Bouchard, 1997; Scarr, 1996).

LOSS OF TALENT

Current assessment practices in education and industry lead to a substantial missed opportunity. Many spatially talented adolescents, for example, may never approach their full potential due to a lack of opportunities to develop their skills. A great loss occurs at talent searches that identify intellectually precocious young adolescents. Current talent search procedures focus on the assessment of mathematical and verbal ability, and many programs require scores within the top 1% to qualify (Colangelo et al., 2004). Most major talent searches do not include tests of spatial aptitude, however, and due to variability in specific ability profiles, these procedures exclude a large numbers of spatially gifted students. One recent estimate suggested over half: Wai et al. (2009), for example, estimated that only 30% of the top 1% in spatial ability also score within the top 1% in mathematical or verbal reasoning (Wai et al., 2009). Consequently, the vast majority of spatially talented young adolescents are being denied admittance to talent search programs.

Going back in time, an example from Terman's (1925–1959) longitudinal study of gifted youth (top 1% in individually administered IQ tests) is instructive. Terman used only the verbally oriented Stanford-Binet (Terman, 1916) test to identify participants, rather than separately assessing verbal and mathematical ability; unfortunately, two subsequent Nobel Laureates in Physics (Shockley and Alvarez) were measured and missed by Terman and his colleagues (Shurkin, 1992). Now that modern talent searches routinely utilize measures of mathematical and verbal reasoning for identification and selection, it is unlikely that they are missing many contemporary young adolescents like Alvarez and Shockley—but whether they are missing a modern-day Thomas Edison or Henry Ford is an open question.

Providing educational opportunities tailored to the strengths of spatially gifted adolescents may be especially important, because it is difficult for students whose intellectual pattern is dominated by spatial ability to reach their full potential with traditional school curricula, where reasoning with numerical and linguistic symbols rather than forms and shapes is the norm (Lohman, 1988). Compared to their intellectual peers who are more mathematically or verbally talented, spatially talented students have lower occupational aspirations and are less likely to obtain an undergraduate degree (Gohm, Humpreys, & Yao, 1998; Humphreys & Lubinski, 1996; Humphreys et al., 1993). They also seem less intellectually engaged by learning environments found in typical high schools, finding it harder to pay attention in class, being less interested in their schoolwork, and studying fewer hours per week (Gohm et al., 1998).

Spatially oriented individuals are not inherently unmotivated, however—it is just that they appear to prefer reasoning with forms and shapes rather than numbers and words. When placed in environments that are aligned with their preferred intellectual–substantive medium, spatially talented students can thrive and even outperform students with commensurate general intelligence but with strengths in other areas (Gohm et al., 1998). However, due to suboptimal educational provisions and a general lack of recognition of what spatially gifted students can accomplish, a large number of potential engineers and physical scientists are likely not earning undergraduate or advanced degrees commensurate with their overall intellectual abilities. Spatially talented individuals may find themselves undereducated and underemployed not by choice but because they have never been made aware of all their options and lacked opportunities to develop in ways congenial with the salient features of their individuality.

For example, over 40 years of SMPY longitudinal research has documented many noteworthy STEM careers among participants scoring in the top 1 in 200 on both the SAT-M and SAT-V by age 12. But, because talent searches do not select participants based on their level of spatial ability, we do not know how students scoring in, say, the top 1 in 500 on spatial ability but who do not qualify for talent searches because their SAT scores are in the 85–90th percentile might do in these programs. We suggest that such students be given a chance. It is likely that these cognitive abilities function in a compensatory fashion—but without empirical research we cannot know for certain. This gap in knowledge needs to be filled.

RECOMMENDATIONS

Talent Searches

The addition of spatial–visualization tests to the practices currently used by most talent search programs would allow for the early identification of spatially gifted young adolescents. More will have to be done than simply adding these assessments, however. Because the majority of talent search programs are geared toward the selection of students whose intellectual strengths focus on mathematical or verbal reasoning, the educational interventions they offer are designed to further develop these strengths. In order to fully support the needs of the spatially gifted, talent search programs will need to consider adjusting preexisting programs or develop new interventions more focally devoted to their salient mode of thought; drawing on coursework in architecture, engineering, robotics, and physical science laboratories is likely an excellent place to take advantage of this exciting opportunity for curriculum development (Wai et al., 2009).

Curriculum Redesign

Another aspect of students whose dominant intellectual orientation is spatial visualization is a pragmatic–realistic outlook on learning, work, and life. This, when coupled with their preferences for creating and manipulating inorganic objects, rather than ideating about abstract mathematical–linguistic symbolic material (Lubinski & Benbow, 2006; Su, Rounds, & Armstrong, 2009; Webb et al., 2007), as evidenced by the activities they pursue in their leisure time: building models, cooking, drawing, repairing, sewing, woodworking (Gohm et al., 1998; Humphreys et al., 1993), clues for developing better learning opportunities for them are brought into focus.

For example, introducing new classes with more hands-on content (e.g., robotics) and increasing the amount of laboratory work in current science classes may not only encourage engagement among spatially talented students but also provide them with a strong knowledge foundation should they choose to pursue a STEM degree (Webb et al., 2007). Additionally, spatial aptitude is negatively related to social service interests and working with people on interpersonal matters (Schmidt, Lubinski, & Benbow, 1998; Smith, 1964). Allowing spatially talented students to work on team projects is likely to be best achieved by structuring tasks around building or creating concrete products and, ideally, in groups of spatially oriented students or like-minded peers. If high schools could be encouraged to develop more club-based opportunities in, say, architecture, engineering, and robotics as they typically have for book and math clubs, this would also likely contribute to the positive development of more spatially orientated students.

Similarly, spatially talented students often find traditional English and humanities courses among their least favorite, but these courses are a curricular cornerstone and unavoidable. So, perhaps initially, adding science fiction novels (Gohm et al., 1998) or biographies of scientists and inventors (Webb et al., 2007) could render these classes more interesting for this special population of intense nonverbal ideators. As they mature, and as they develop an appreciation for literature, they will be better prepared for branching out and discovering other intellectually enriching content. Another approach might be to capitalize on the fact that spatially oriented learners value the *discovery of truth* (Schmidt et al., 1998). So, for example, spatially talented students could perhaps become more appreciative of the humanities if some literary works are portrayed as attempts to discover fundamental truths about the universe, rather than simply the “great books.”

Higher Education Admissions

STEM commitment and success demands high mathematical and high spatial aptitude, yet current admissions standards only take into account one of these abilities. In and of itself this oversight is problematic enough, but the manner in which this is done creates additional complications. Consider the following: The mathematical reasoning section of the SAT and GRE are compromised by ceiling effects among students attracted to STEM areas—at age 18 and 22, respectively, these assessments cannot discriminate between those who are “merely” talented and those who are profoundly talented in mathematical reasoning (Kell, Lubinski, & Benbow, 2013; Lubinski et al., 2001). Because of this, admissions committees often heavily weigh verbal reasoning scores when making decisions, with the idea of securing a more able student body (Lubinski, 2010a, 2010b). However, students with markedly more impressive verbal ability relative to spatial ability tend to be more attracted to disciplines and occupations outside of STEM (Kell, Lubinski, Benbow, & Steiger, 2013; Wai et al., 2009)—recall Figure 5. Adding emphasis to verbal scores in conjunction with suboptimal ceilings on mathematical reasoning tests sets the stage for an inadvertent side effect, by putting applicants whose intellectual profile is dominated by spatial–visualization at a marked disadvantage (Lohman, 1994b; Lubinski, 2010b). Current admissions practices, ironically, are likely selecting out some of the most promising candidates for STEM persistence and success.

In addition to assessing spatial ability for selecting STEM students (Lubinski, 2010b), graduate programs would do well to take into account applicants' scores on GRE knowledge-based subject tests (e.g., mathematics, physics). Subject tests are better predictors of graduate student success than the general (GRE) test (Kuncel, Hezlett, & Ones, 2001; see also Austin & Hanisch, 1990). Considering the extent to which spatial aptitude is implicated in obtaining a STEM degree and maintaining a commitment to STEM areas, these tests serve to some extent as surrogates for spatial ability. Considering the importance of STEM innovation for remaining competitive in the global economy (Friedman, 2007; Friedman & Mandelbaum, 2011), considering these assessment modifications, and at least experimenting with them in conjunction with procedures now in place for student selection, seems logical. For identifying truly outstanding talent for creativity and innovation in STEM, assessing quantitative and spatial reasoning with measures having adequate ceilings and devoting commensurate attention to knowledge based assessments is empirically grounded and has worked cross-culturally (Friedman, 2007, pp. 367–368).

CONCLUSION

There is widespread recognition that the United States is not adequately leveraging its human capital resources to promote continuing STEM innovation (National Academy of Sciences, 2010; National Science Board, 2010). Failure to remain at the cutting edge in STEM could have serious ramifications for national prosperity (Rindermann & Thompson, 2011) and the current quality of life enjoyed by American citizens. Though troubling, this state of affairs may also provide the impetus necessary for a full appreciation of spatial talent to finally develop. Indeed, the National Science Board (2010) specifically recommended that spatial ability be a major target of efforts to identify and cultivate tomorrow's STEM innovators. It is key to remember, however, that though the spatially talented constitute a precious human capital resource, they are not a commodity to be mined and then forgotten when their skills are no longer in such critical demand (Benbow & Stanley, 1996). Spatially gifted adolescents deserve to have opportunities made available to them not only because they are at promise for STEM achievement but also because it is their right to choose whatever occupation they feel suited for (Paterson, 1957). For years, we have had reliable scientific information on the importance of spatial ability—it is time we put it to better use.

AUTHOR NOTE

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