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Spatial ability and STEM: A sleeping giant for talent identification and development

David Lubinski *

Department of Psychology and Human Development, Peabody 0552, 230 Appleton Place, Vanderbilt University, Nashville, TN 37203, United States.

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ABSTRACT

Spatial ability is a powerful systematic source of individual differences that has been neglected in complex learning and work settings; it has also been neglected in modeling the development of expertise and creative accomplishments. Nevertheless, over 50 years of longitudinal research documents the important role that spatial ability plays in educational and occupational settings wherein sophisticated reasoning with figures, patterns, and shapes is essential. Given the contemporary push for developing STEM (science, technology, engineering, and mathematics) talent in the information age, an opportunity is available to highlight the psychological significance of spatial ability. Doing so is likely to inform research on aptitude-by-treatment interactions and Underwood's (1975) idea to utilize individual differences as a crucible for theory construction. Incorporating spatial ability in talent identification procedures for advanced learning opportunities uncovers an under-utilized pool of talent for meeting the complex needs of an ever-growing technological world; furthermore, selecting students for advanced learning opportunities in STEM without considering spatial ability might be iatrogenic.

In celebrating the distinguished career of Thomas J. Bouchard, Jr., it seems fitting to recall a vivid memory of what it was like sitting in on Bouchard's course in individual differences (or "IDs"), first as a student and, subsequently, as his graduate teaching assistant for the same course. Twice a week, students would listen to Bouchard analyze empirical studies and break them apart bone-by-bone. Many would appear numb as their deeply held suppositions about human behavior were found to have little empirical basis. Like Donald G. Paterson's course in IDs, which prior generations of Minnesota graduate students experienced, students left Bouchard's course with new perspectives. Students having the privilege of experiencing one of these two intellectual giants – over the 80-year period they successively taught IDs at Minnesota – could never again look at human behavior through the same lens. Their newly acquired knowledge base forever changed how they viewed the human condition and the complex tensions surrounding social order, liberty, and individual differences (Wells, 1937).

One of the more memorable things about Bouchard's course was that, occasionally, after presenting a compelling empirical demonstration to the class, on the power that psychological variables can hold for predicting important socially-valued outcomes (educational achievements, occupational accomplishments, or life in general), Bouchard would turn to the class and say: "See, see, see what happens when psychologists choose to study *real* variables." This point of view was not unrelated to that of Bouchard's colleague Paul E. Meehl; Meehl would occasionally wonder out loud whether it would be scientifically prophylactic to require graduate students in psychology to take a minor in a natural science like biology or genetics. By going so, Meehl speculated, they might be able to recognize a meaningful scientific contribution, if they should ever happen to encounter one in psychology! These two anecdotes set the stage for this contribution, regarding one of Bouchard's favorite psychological variables, spatial ability. For decades, spatial ability has surfaced as a salient characteristic of young adolescents who go onto develop expertise in science, technology, engineering, and mathematics (STEM), yet applied psychologists and talent development researchers have failed to fully recognize this important dimension of human individuality.[1] Contemporary discourse on the importance of identifying and nurturing STEM talent affords an opportunity to correct for this neglected "*real* variable."

1. Spatial ability and STEM: decades of longitudinal research

For example, during the same year Sputnik was launched, a little known report, *Scientific Careers*, was published on the psychological characteristics of individuals harboring STEM talent. This report was based on a NSF committee chaired by Donald Super, who assembled a distinguished team of psychologists (Harold

[1] The referent generality of spatial ability extends well beyond STEM domains and encompasses among other things the creative arts in particular (Humphreys, Lubinski, & Yao, 1993). This article, however, will be restricted to STEM domains. For further reading on the educational and psychological significance of spatial ability, see Lohman (1988, 1994, 1996).

* Tel.: +1 615 343 1195.
E-mail address: david.lubinski@vanderbilt.edu

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Papinsky, Anne Roe, Leona Tyler, and others) to conduct a literature review and issue recommendations for future research and theory construction on identifying and developing exceptional careers in engineering and the physical sciences. Their report is impressive for many reasons. First, many of their conclusions and recommendations (Super & Bachrach, 1957), based on the empirical evidence available at the time, were supported by subsequent longitudinal findings based on normative samples (Austin & Hanisch, 1990; Gohm, Humphreys, & Yao, 1998; Humphreys & Yao, 2002; Humphreys et al., 1993) and on samples of intellectually precocious youth (Shea, Lubinski, & Benbow, 2001; Wai, Lubinski, & Benbow, 2009; Webb, Lubinski, & Benbow, 2007). Like Smith (1964) comprehensive review of spatial ability, Super and Bachrach (1957) document that exceptional general intellectual potential is characteristic of engineers and physical scientists at early ages; however, they went onto stress that specific abilities – especially mathematical reasoning and spatial ability – are also salient features of their individuality. Moreover, they also noted the importance of scientific interests, and called for additional longitudinal research, for instance, following young adolescents over 10- to 15-years for ascertaining how these and other personal attributes, and contrasting opportunities and supports, factor into differential development.

During the years between Super and Bachrach (1957) and Smith (1964), John C. Flanagan et al. (1962) launched Project Talent, which was expressly the kind of longitudinal study that Super's NSF team envisioned. Because of its comprehensiveness and size, longitudinal findings from Project TALENT are among the most compelling for illustrating the role that spatial ability plays in developing expertise in STEM. Project TALENT's initial data collection occurred in 1960, and consisted of a stratified random sample of the USA's high school population. Students in the 9th through 12th grades were assessed on a wide range of tests and questionnaires over a one-week period, and the entire sample included roughly 50,000 males and 50,000 females per grade level, for a total *N* of approximately 400,000. Included in the tests were a number of measures designed to assess cognitive abilities (e.g., general intelligence and specific abilities: mathematical, verbal, and spatial reasoning). Project TALENT also included longitudinal data taken 1, 5 and 11 years after graduation from high school (Wise, McLaughlin, & Steel, 1979). A number of longitudinal studies based on Project TALENT's 11-year follow-up underscore the importance of spatial ability for accomplishments in STEM disciplines (Austin & Hanisch, 1990; Gohm et al., 1998; Humphreys & Lubinski, 1996; Humphreys & Yao, 2002; Humphreys et al., 1993). A recent study comparing these data to modern longitudinal findings from the Study of Mathematically Precocious Youth (SMPY; Lubinski & Benbow, 2006), is especially relevant to understanding the development of STEM talent (Wai et al., 2009).

Wai et al. (2009) focused on participants' highest degree received (bachelor's, master's, or doctorate), the disciplines within which their degrees were earned, and their occupations as a function of general ("*g*") and specific (mathematical, spatial, and verbal) abilities. Fig. 1 graphs the general and specific ability profiles of Project Talent participants earning terminal degrees in various disciplines. Because highly congruent findings were observed for all four cohorts, grades 9–12, the cohorts were combined. High general intelligence and an intellectual orientation dominated by high mathematical and spatial abilities, relative to verbal ability,

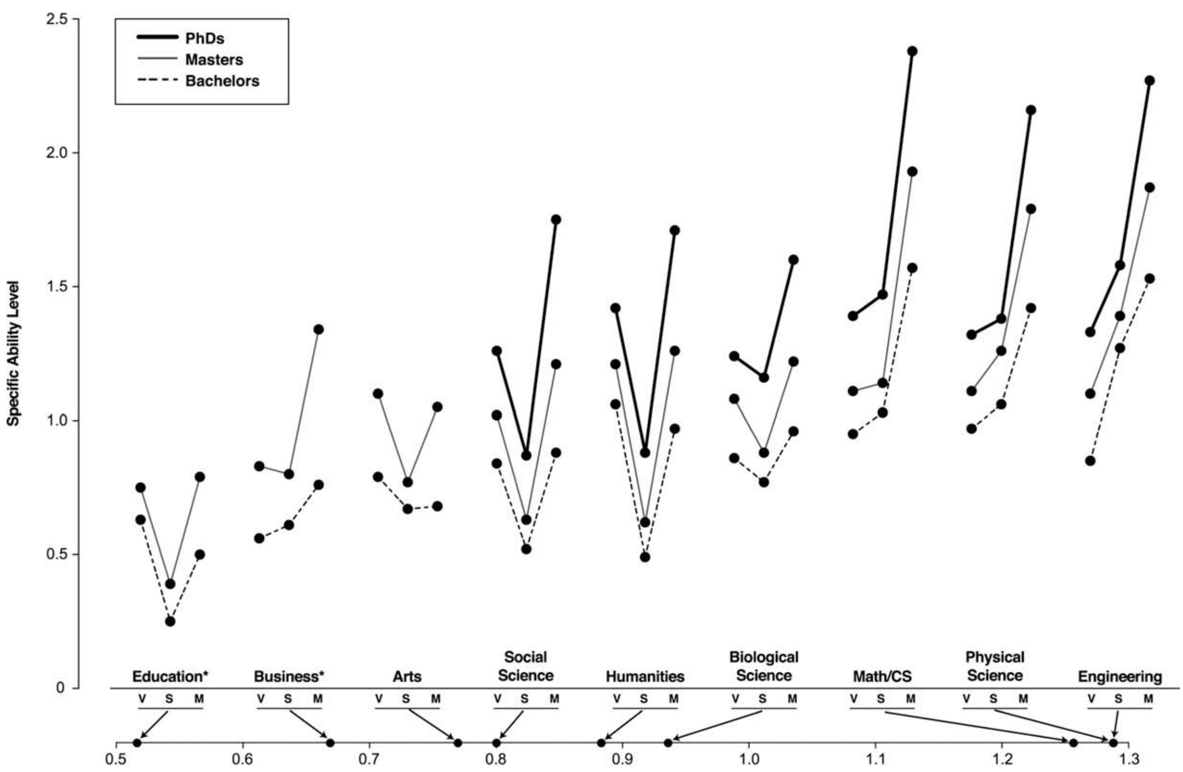

Fig. 1. Average *z*-scores of participants on spatial, math, and verbal ability for bachelor's degrees, master's degrees, and PhDs are plotted by field. The groups are plotted in rank order of their normative standing on *g* (S + M + V) along the *x*-axis and the line with the arrows from each field pointing to it indicates on the continuous scale where they are in general mental ability. 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 (Males + Females) were (for bachelor's, master's, and doctorates respectively): engineering (1143, 339, and 71), physical science (633, 182, and 202), math/computer science (877, 266, and 57), biological science (740, 182, and 79), humanities (3226, 695, and 82), social science (2609, 484, and 158), arts (615, M = 171), business (2386, M + D = 191), and education (3403, M + D = 1505). *For education and business, masters and doctorates were combined because the doctorate samples for these groups were too small to obtain stability (*N* < 30). From Wai et al. (2009).

were salient characteristics of individuals who pursued advanced educational credentials in STEM. Their ability level and pattern occupies a different region in the intellectual space defined by these dimensions, relative to participants who earn undergraduate and graduate degrees in other domains. Moreover, for all three degree groupings in Fig. 1, the incremental validity of spatial ability beyond mathematical and verbal ability was evaluated. For each terminal degree, STEM degrees were dummy coded 1, and non-STEM coded 0. Multiple regression analyses were then run to determine whether spatial ability accounted for additional criterion variance (STEM, non-STEM) beyond mathematical and verbal ability; across all three analyses, spatial ability accounted for an average of 4% additional variance beyond mathematical and verbal ability.

Some important features in Fig. 1 are worth highlighting: In *z*-score units, group means on general intellectual ability, arrayed on the *x*-axis, for four-year and graduate degrees, range from just over .50 (Education) to just over .90 (Biology), a difference of approximately .40 standard deviation units; this difference in effect size units is the same as that observed between Biology and the three STEM educational groupings (viz., just under 1.3 to just over .90, or approximately .40). This is a substantively significant general ability difference. Yet, there is an important difference across these educational groups in specific-ability-pattern that is arguably more important: 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 (with one exception: four-year degrees in business). Adolescents who subsequently earned advanced educational credentials in STEM manifested a spatial–verbal ability pattern opposite that of those who ultimately earned educational credentials in other areas. This is psychologically informative for several reasons. Obviously, STEM disciplines place a premium on nonverbal ideation indicative of quantitative and spatial reasoning, but there are other important psychological reasons for examining these differential ability patterns (Lubinski & Benbow, 2000, 2006). In particular, the distinctive ability profiles revealed in Fig. 1, namely, the spatial > verbal ability pattern characterizing STEM and the spatial < verbal ability pattern characterizing non-STEM disciplines, covary with contrasting motivational proclivities in education and the world of work. And these in turn are likely to have differential implications for commitment to developing expertise and persistence in STEM (Ackerman, 1996; Ackerman & Heggestad, 1997; Schmidt, Lubinski, & Benbow, 1998; Webb et al., 2007).

Verbal ability, for example, manifests positive correlations in the mid-20s with educational–vocational interests in the humanities and social pursuits, whereas for spatial ability these correlations are of the same magnitude but opposite sign. Similarly, spatial ability manifests correlations in the mid-20s with interests in engineering and mechanical pursuits, whereas for verbal ability these correlations are of the same magnitude but opposite sign (Ackerman, 1996; Ackerman & Heggestad, 1997; Schmidt et al., 1998; Webb et al., 2007). Among people and groups who differ markedly in spatial versus verbal ability (spatial >> verbal, or spatial << verbal ability), these small correlations of both signs eventuate in huge motivational differences in orientation toward educational and occupational opportunities for learning about and working with *people* versus *things* (Su, Rounds, & Armstrong, 2009) or *organic* versus *inorganic* subject matter (Lubinski & Benbow, 2006).

That distinct constellations of educational–vocational interests co-occur with contrasting intellectual profiles suggests that students with salient verbal relative to spatial abilities are also tuned to contrasting affordances in learning and work settings relative to students whose specific ability profile is more dominated by spatial relative to verbal ability (Fig. 1). There also is evidence to suggest that students with mathematical > spatial > verbal or spatial > mathematical > verbal profiles are intellectually turned off by curricula that is overly abstract in verbal-linguistic content (Humphreys & Lubinski, 1996; Humphreys et al., 1993). Even with general intellectual ability held constant, contrasting intellectual patterns of specific abilities are associated with distinctive motivational tendencies (Lubinski, Webb, Morelock, & Benbow, 2001; Webb et al., 2007), different passions for personal fulfillment (Ackerman, 1996; Ackerman & Heggestad, 1997; Dawis & Lofquist, 1984), and different requirements for meaningful life (Lubinski, 1996, 2000; Lubinski & Benbow, 2000, 2001).

It is interesting that these and other longitudinal findings on spatial ability, replicated over multiple decades and multiple data sets have not resulted in exploiting the psychological significance of this powerful construct in educational and occupational settings. Ten years ago, the late Snow (1999) commented: “There is good evidence that [spatial ability] relates to specialized achievements in fields such as architecture, dentistry, engineering, and medicine. ... Given this plus the longstanding anecdotal evidence on the role of visualization in scientific discovery, it is incredible that . . . there has been so little programmatic research on admissions testing in this domain” (p. 136). More recently, in an edited volume honoring Snow’s life work on aptitude/treatment interactions, the editors concluded: “If spatial-mechanical reasoning, . . . is a component of achievement in some walks of science, then educators and program evaluators should be giving it direct attention” (Corno, Cronbach et al., 2002, p. 73). Yet, as a recent exchange in the *Educational Researcher* underscores, developing assessment tools for student selection and implementing their use in practice is complex, difficult, and political (Atkinson & Geiser, 2009; Linn, 2009). Nevertheless, there is one domain wherein spatial ability measures could be expressly implemented to achieve an appreciable social yield.

2. Intellectually precocious youth

This domain is talent searches designed to meet the needs of intellectually precocious youth through summer residential programs consisting of accelerative learning experiences (Benbow & Stanley, 1996; Colangelo, Assouline, & Gross, 2004; Stanley, 2000). For four decades now, talent searches have administered college entrance exams like the SAT to 7th and 8th graders scoring in the top few percentage points on any of a variety of achievement tests routinely administered in their schools. Since talent searches first began in the US in 1972, when Julian C. Stanley (1996; Keating & Stanley, 1972) launched the first utilizing the SAT to just under 500 participants, they have now grown to assess approximately 200,000 7th and 8th graders annually. We now know several things about the learning rates and future outcomes of these young adolescents achieving exceptional scores on college entrance exams.

For example, adolescents scoring 500 or higher on SAT-M or SAT-V by age 13 (top 1 in 200), can assimilate a full high school course (e.g., chemistry, English, and mathematics) in three weeks at summer residential programs for intellectually precocious youth; yet, those scoring 700 or more (top 1 in 10,000), can assimilate at least twice this amount (Benbow & Stanley, 1996; Colangelo et al., 2004; Stanley, 2000). These assessments are critical, therefore, for structuring educational curricula, because the exceptionally able require different opportunities for optimal development than the able (Lubinski, Benbow, Shea, Eftekhari-Sanjani, & Halvorson, 2001; Muratori, Stanley et al., 2006; Wai, Lubinski, Benbow, & Steiger, in press), the former need a more abstract, deeper, and faster-paced curriculum to avoid boredom. Furthermore, individual differences in learning rates between the able and the exceptionally able portend differences in creative and occupational accomplishments many years later. Like their earlier academic accomplishments, the occupational accomplishments of the profoundly gifted tend to develop at an accelerated pace with greater depth. The profoundly gifted simply have greater capacity for accomplishment and creative contributions (Park, Lubinski, & Benbow, 2007, 2008).

For example, the base rate for earning a doctorate in the US is 1% (i.e., JD, MD, or Ph.D.). In 20-year follow-up studies of adolescents identified by age 13, for example, 30% of participants scoring SAT-M or SAT-V $\geqslant$ 500 secured doctorates, compared to 50% for those scoring $\geqslant$ 700 (Benbow, Lubinski, Shea, & Eftekhari-Sanjani, 2000; Lubinski, Benbow, Webb, & Bleske-Rechek, 2006)! That a 2-h test can identify 12 year olds who will earn this ultimate educational credential at 50 times base rate is remarkable. Moreover, a 200 point difference in SAT scores by age 13 (500 versus 700) eventuates in marked differences by middle age in income, patents, refereed literary and scientific publications, and secured tenure track academic positions at top US universities (cf. Lubinski et al., 2006; Park et al., 2007, 2008; Wai, Lubinski, & Benbow, 2005). Over one third of the ability range is found within the top 1% of ability; above-level testing affords valid assessments of individual differences within this range; and these differences make a difference in school, work, and life.

However, as impressive as these findings are, there is room for improvement. Given the intercorrelations between mathematical, spatial, and verbal abilities, approximately half of the young adolescents in the top 1% in spatial ability do not qualify for talent searches or summer residential programs for intellectually talented youth when selection criteria are restricted to the top 1% in mathematical or verbal ability (Wai et al., 2009). By incorporating measures of spatial ability, talent searches could prevent this loss, and students primarily talented in mathematical or verbal reasoning could profit as well by gaining a more comprehensive purchase on their intellectual strengths and relative weaknesses.

For example, in the late 1970s, Julian Stanley administered a number of tests of spatial–mechanical reasoning to several hundred talent search participants attending summer residential programs based on their SAT-M or SAT-V scores. Subsequently, through the Study of Mathematically Precocious Youth (SMPY; Lubinski & Benbow, 2006; Shea et al., 2001), these participants were followed-up at three time points: 5-, 10-, and 20-years later (ages 18, 23, and 33). To my knowledge, these findings constitute the first demonstration that spatial ability adds incremental validity (beyond quantitative and verbal reasoning measures) in the prediction of educational–occupational criteria among talent search participants initially identified before age 13 on the basis of SAT-Math and SAT-Verbal scores. Subsequent longitudinal findings have shown that spatial ability adds incremental validity to the SAT and comprehensive educational–vocational interest inventories in the prediction of educational–vocational criteria (Webb et al., 2007).

Some of Shea et al's (2001) longitudinal outcomes, which include favorite and least favorite high school course (age 18 follow-up), college major (age 23 follow-up), and occupation (age 33 follow-up) are shown in Fig. 2, as a function of their standing

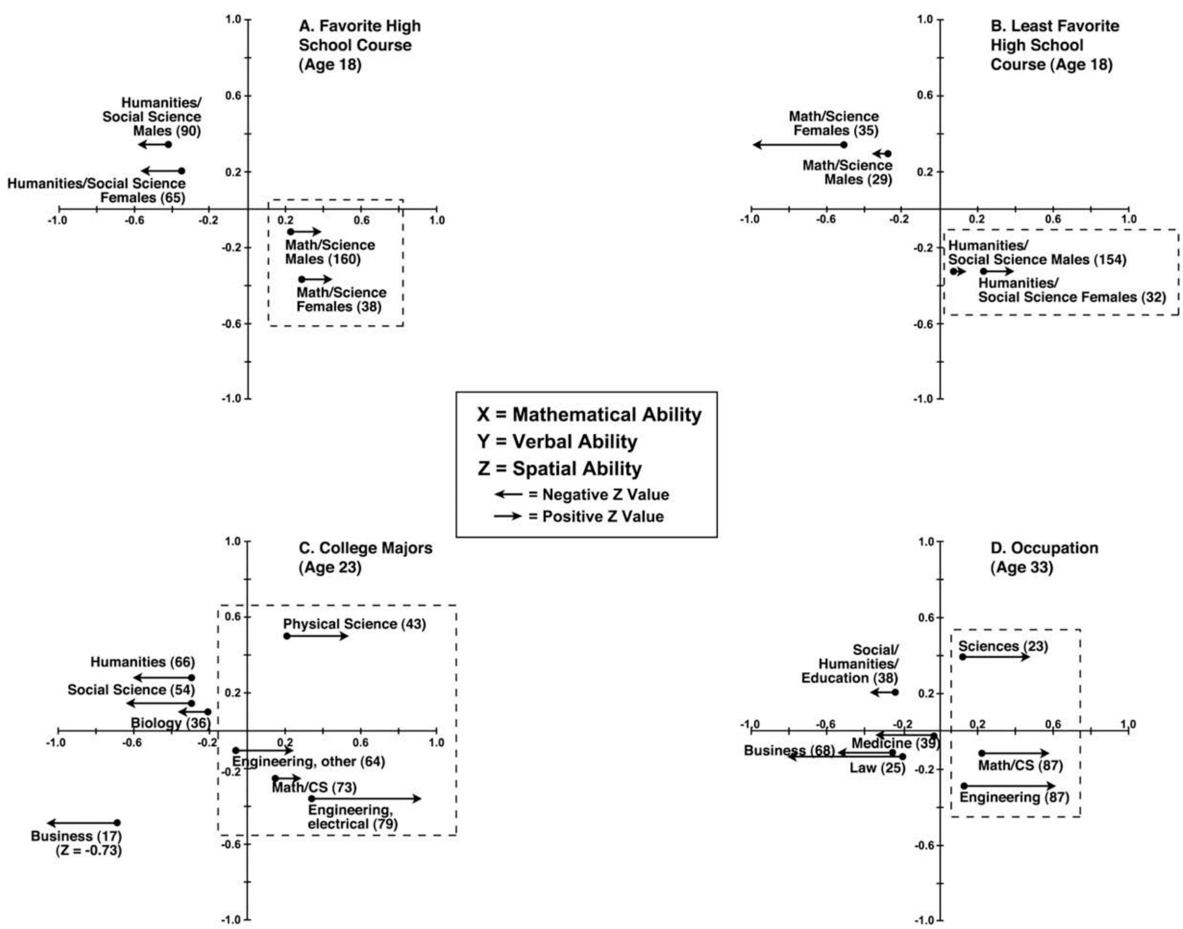

Fig. 2. Shown are trivariate means for (Panel A) favorite and (B) least favorite high school course at age 18, (C) college majors at age 23, and (D) occupation at age 33. Math, verbal, and spatial ability are on the *X*, *Y* and *Z*-axes, respectively (arrows to the right indicate a positive *Z* value; arrows to the left indicate a negative *Z*-value). Panels A and B are standardized within sex, C and D across sexes. For Business in Panel C it is noted that the length of the arrow is actually $Z = -0.73$. Figure adapted from Shea et al. (2001).

on these three abilities assessed at age 13 in standard deviation units. SAT-M is scaled on the *x*-axis, SAT-V on the *y*-axis, and Spatial Ability on the *z*-axis (all notated by arrows in standard deviation units: arrows to the right are positive values, and arrows to the left are negative values). Essentially this is a three dimensional graph put in a two dimensional representation. To visualize the location of each group in three-dimensional space, imagine the arrows to the right projecting outward and arrows to the left projecting inward, both orthogonal to *x* and *y*; in this way, the psychological distance between these criterion groups can be pictured in the space defined by the three ability dimensions in standard deviation units. Dotted lines are placed around the STEM groups to highlight their consistent pattern across all three time points. These patterns reflect those observed in Project Talent participants whose 11-year longitudinal follow-up was conducted before these SMPY participants were identified in the late 1970s at age 13 (Wai et al., 2009).

It is important to keep in mind that the SMPY participants were identified as intellectually talented in early adolescence (top 0.5% for their age group on mathematical or verbal ability), nevertheless, their patterns of specific abilities are readily distinguished by their educational–occupational group membership. With respect to the focal construct under analysis here, the consistently distinguished levels of spatial ability among adolescents who subsequently go onto earn STEM educational degrees and occupations, relative to adolescents who secure educational credentials and occupations in other areas, reveals the importance of spatial ability in STEM arenas (as indicated by rightward-pointing arrows across all four panels of Fig. 2).

Furthermore, consistently, lower levels of spatial ability, indicated by arrows pointing to the left, were associated with domains outside of STEM. For example, take the engineering group in Panel D, this group's *z*-score on spatial ability was .55 (the length of the rightward pointing arrow), whereas the group of lawyers' *z*-score mean on spatial ability was −.60 (the length of the leftward pointing arrow). This means that these two occupational groupings were 1.15 standard deviations apart on spatial ability (among intellectually talented adolescents subsequently employed at age 33), even though both groups were above the normative mean on spatial ability at age 13 (Shea et al., 2001). Hence, relative strengths and weaknesses contribute to contrasting outcomes in education and the world of work. Jointly, the successive panels in Fig. 2 demonstrate how spatial ability operated over the lifespan (after high school, after college, and at age 33) regardless of whether it was measured. That is, whereas quantitative and verbal reasoning measures were used to identify these participants, and similar measures were subsequently used throughout their educational careers as selection tools, spatial ability was only assessed experimentally at the time of their initial identification, and spatial ability was not then nor is it currently being used in educational selection for advanced degrees or professional careers. Yet, the role spatial ability played for these intellectually talented youth in the domains in which they achieved is clear to the naked eye. As with the normative data collected by Project Talent (Fig. 1), among intellectually precocious participants, the STEM groups were higher on spatial ability relative to the other groups. And the co-variation between educational–vocational interest measures and specific abilities observed in adult samples (Ackerman, 1996; Ackerman & Heggestad, 1997) has been replicated among intellectually talented youth (Schmidt et al., 1998; Webb et al., 2007).

3. Discussion

The findings and literature reviewed here suggest that individuals who go onto achieve educational and occupational credentials in STEM tend to be distinguished by salient levels of spatial ability, relative to verbal ability, during early adolescence. Indeed, their level of mathematical and spatial reasoning ability is markedly above the norm of their age-matched peers (Gohm et al., 1998; Humphreys et al., 1993; Smith, 1964; Super & Bachrach, 1957; Wai et al., 2009; Webb et al., 2007). Moreover, spatial ability covaries with preference patterns correspondent with the motivational (interests-values) profiles of individuals with STEM degrees and occupations (Ackerman, 1996; Ackerman & Heggestad, 1997; Lubinski, Benbow et al., 2001; Schmidt et al., 1998; Webb et al., 2007). Given the extent to which these robust trends have been documented for decades, we appear to be in a position similar to that of research traditions involving clinical versus statistical prediction (Dawes, Faust, & Meehl, 1989; Grove & Meehl, 1996; Meehl, 1986), and the relation between general intellectual ability and abstract learning (Corno, Cronbach et al., 2002; Sackett, Kuncel, Arneson, Cooper, & Waters, 2009) and complex work performance (Schmidt & Hunter, 1998, 2004), that is, these consistent findings are solid enough to establish an empirical generalization: *Individual differences in spatial ability contribute to learning, the development of expertise, and securing advanced educational and occupational credentials in STEM*.

This empirical generalization has several implications. For example, if selection criteria for the identification of intellectually talented youth were augmented with measures of spatial ability, experimentation could proceed on curriculum design to meet the advanced learning needs of spatially precocious students with strong preferences for ideating about forms and shapes. Modern talent search procedures, exclusively restricted to selection criteria involving mathematical and verbal reasoning measures, currently miss approximately half of the top 1% in spatial ability (Wai et al., 2009). This population constitutes an untapped pool of talent for whom experimentation is desperately needed for constructing opportunities for actualizing their potential. Specifically, curricula that focus on transforming inorganic material, advanced learning opportunities in domains such as architecture, engineering, robotics, and physical science laboratories are likely candidates for what spatially talented adolescents need to become more fully engaged intellectually. This also corresponds with the types of hobbies spatially talented adolescents engage in, relative to mathematically and verbally precocious students; the former tend to prefer working with their hands and shaping and transforming objects, as in gardening, building models, repairing, sewing, cooking, drawing, and painting (Humphreys et al., 1993). While the importance of spatial ability has been alluded to in treatments of exceptional human accomplishments, and spatial ability is clearly seen as distinctive from mathematical and verbal reasoning ability (Carroll, 1993; Snow & Lohman, 1989; Snow, et al., 1996), systematic empirical work has been rare.

4. Broader Psychological Implications

The findings reviewed here touch on broader psychological topics and corollary issues. For example, for years methodologically oriented psychological scientists have bemoaned the slow progress in the human psychological sciences (Cronbach, 1975; Dawes, 1994; Dunnette, 1966; Lykken, 1991) and lack of "cumulative character that is so impressive in disciplines like astronomy, molecular biology, and genetics" (Meehl, 1978, p. 807), longitudinal findings on spatial ability and how it operates in the context of other individual differences affords a conspicuous counter example to this familiar concern. Powerful cumulative findings, which harbor tremendous potential for socially-valued outcomes, have consistently emerged over multiple decades for spatial ability. Yet, for decades, the available longitudinal evidence on spatial ability has been routinely ignored by psychological specialties in the position to develop it further and put it into practice (Gottfredson, 2003). Psychologists simply need to choose to incorporate and study this "*real* variable." With respect to STEM, other scientifically compromised practices require attention as well. For example, while quantitative reasoning ability is not neglected by the psychological sciences in regards to the identification and training of STEM talent, its full scope has not typically been assessed. This constitutes another form of neglect – neglecting to assess the breadth of an attribute, as opposed to neglecting the attribute altogether. Consider the following.

All of the relationships observed in Fig. 2 utilizing SAT-M at age 13 would be suppressed if these intellectually precocious participants were assessed on this measure at age 18. By age 18, students functioning at this level of intellectual development have outgrown the SAT-M, and essentially all of them score near its (800) ceiling as high school seniors (Lubinski, Webb et al., 2001; Park et al., 2007, 2008). By the time they reach age 18, the SAT is no longer able to distinguish the able from the *exceptionally* able. This problem is not forestalled by the Graduate Record Exam (GRE-Quantitative), the selection tool utilized in the United States for admission into prestigious graduate training programs. Based on approximately 2.5 million GRE test takers assessed in 2002–2005, 30% scored ⩾ 700 (out of a top possible score of 800) on GRE-Q (ETS data: all examinees tested between 1 July 2002 and 30 June 2005, N GRE-V = 1,245,878, N GRE-Q = 1,245,182). The GRE-Verbal was not compromised by ceiling effects, with only 3% scoring ⩾ 700. Indeed, the GRE-Q mean of 591, with a standard deviation of 148, reveals that the mean is 1.4 standard deviations from the GRE-Q ceiling; whereas the GRE-V mean of 467, with a standard deviation of 118, places this mean at 2.8 standard deviations from the GRE-V ceiling (twice the distance). This results in 10 times as many scores ⩾ 700 for GRE-Q than GRE-V!

Of the two most critical specific abilities for commitment to and excellence in STEM educational–occupational tracks, selection criteria for advanced education and training in the US are severely compromised by ceiling effects for one (mathematical reasoning) while the other (spatial ability) is totally neglected. Yet, the importance of identifying and developing STEM talent has never been more urgent, with many national reports documenting the need (American Competitiveness Initiative, 2006; National Academy of Science, 2005).

It is informative to reflect on the manner in which Microsoft developed its research center in Beijing; consider this report by Thomas Friedman (2005) in his award-winning book, "*The World is Flat*."

> Kai-Fu Li is the Microsoft executive who was assigned by [Bill] Gates to open the Microsoft research center in Beijing. My first question to him was, "How did you go about recruiting the staff?" Li said his team went to universities all over China and simply administered math, IQ, and programming tests to Ph.D.-level students or scientists.
> "In the first year, we gave about 2000 tests all around," he said. From the 2000, they winnowed the group down to 400 with more tests, then 150, "and then we hired 20." They were given two-year contracts and told that at the end of 2 years, depending on the quality of their work, they would either be given a longer-term contract or granted a postdoctoral degree by Microsoft Research Asia. Yes, you read that right. The Chinese government gave Microsoft the right to grant postdocs. Of the original twenty who were hired, twelve survived the cut. The next year, nearly four thousand people were tested. After that, said Li, "we stopped doing the test. By that time we became known as the number one place to work, where all the smart computer and math people wanted to work... We got to know all the students and professors. The professors would send their best people there, knowing that if the people did not work out, it would be their credibility [on the line]. Now we have the top professors at the top schools recommending their top students. A lot of students want to go to Stanford or MIT, but they want to spend 2 years at Microsoft first, as interns, so they can get a nice recommendation letter that says these are MIT quality." Today Microsoft has more than two hundred researchers in its China lab and some four hundred students who come in and out on projects and become recruiting material for Microsoft (Thomas L. Friedman, *The World is Flat*, 2005, pp. 266–267)

If a deeper conceptual/theoretical understanding of STEM educational–occupational choice, performance after choice, and career persistence within choice is to be accomplished, and if truly exceptional world-class performances are to be understood from a scientific point of view, the breadth of human capability along with its distinctive qualities needs to be taken into account (Lubinski, 2010). Indeed, if Cronbach's (1957) two disciplines of scientific psychology are to be implemented with precision, and if Underwood's (1975) recommendation to use individual differences as a crucible for theory construction is to be practiced meaningfully, then we not only have to measure key individual differences attributes but we also need to measure their full range.

Furthermore, given the profile differences in specific-ability-pattern associated with advanced educational credentials and occupations in STEM (Figs. 1 and 2), it is important to consider the possibility of an iatrogenic effect of selection procedures currently in place: If schools of engineering, say, are attempting to be more selective with respect to the intellectual profile of their graduate student body, by selecting students based on their GRE composite (GRE-Q + GRE-V), they could actually be working against themselves: Verbal ability could be operating as a suppressor variable and systematically precluding through indirect selection students exceptionally talented in spatial ability but relatively unimpressive in verbal ability; that is, many of these unselected students may be truly exceptional in reasoning with forms, patterns, and shapes.

Eysenck (1995) noted that the cognitive repertoire can be outlined in many important respects by two dimensions: *g* and a bipolar spatial-verbal factor (wherein mathematical reasoning is absorbed by "*g*") – a rudimentary model of some of Bouchard's recent work (Johnson & Bouchard, 2007a, 2007b). That mathematical reasoning is absorbed by "*g*" in a two-factor model (viz., g + bipolar spatial-verbal factor) is supported by data found in Fig. 1. Individual differences in mathematical reasoning parallel the well-known intellectual hierarchy of contrasting disciplines with respect to general intelligence (or, "*g*"), after that, what is distinctive among participants with advanced STEM educational degrees is their spatial ability > verbal ability profile relative to participants earning advanced degrees in non-STEM disciplines who manifest the inverse pattern (viz., a spatial ability < verbal ability profile). Selecting prospective engineering students with an intellectual profile more distinguished by verbal rather than spatial ability, no matter how bright overall, is unlikely to build a persistent student body devoted to excellence in and commitment to engineering over protracted intervals, relative to other selection procedures. They may be impressive students, but it is likely that their regnant mode of thought is dominated by reasoning with verbal-linguistic symbols as opposed to ideating about figures and shapes and quantifying their empirical relationships.

This concern becomes more salient given the low ceiling on the GRE-Q, because high GRE Q + V composite scores are likely to reflect an overabundance of students whose intellectual repertoire is more distinguished by truly exceptional verbal ability. Moreover, given the nonintellectual correlates of specific abilities (Ackerman, 1996; Ackerman & Heggestad, 1997; Schmidt et al., 1998; Webb et al., 2007), concerns about selecting students committed to STEM are reinforced. Choosing to ignore an important individual differences variable (like spatial ability), or choosing not to assess individual differences within truly outstanding ranges (like mathematical reasoning ability) does not prevent these individual differences and their attendant motivational covariates from operating (Dawis, 1992; Lubinski & Humphreys, 1997; Park et al., 2007, 2008).

Perhaps Karl Popper (1959) said it best, "*The main task of social science ... is to trace the unintended repercussions of intentional human actions*" (p. 281, italics in original). To do this, social scientists aiming to understand the development of STEM talent must utilize all of the available scientific information about the known major determinants of STEM accomplishments and expertise and assess their full range (Lubinski & Benbow, 2006), they must not *neglect aspects* (Castell, 1935; Ellis, 1928), they must utilize *total evidence* (Carnap, 1950), this will not only afford a better understanding of the development of STEM talent, it will engender insight into the intellectual design space operating in the human condition (Lubinski, 2004). Like Paterson (1957) before him, this is something that Bouchard (2009) has contributed to and stressed in multiple contexts over the course of his distinguished career.

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