SUPPLEMENTAL NOTE 1

Intellectual Precocity and Health: Untangling SES and IQ

Early on in research on intellectual precocity, astute observers realized that general intellectual ability and socioeconomic status (SES) are confounded. Barbara Burks (1938; Burks & Kelley, 1928) authored one of the earliest contributions on the analytic issues associated with this conundrum, and proposed adoption studies as a solution; Goodenough (1956, p. 74) offered a compelling design for untangling these two purported causal streams as well. Now, these and other compelling applications are standard methodological tools of biometrically informed designs and have been utilized for some time (Bouchard, 2009; Plomin et al., 2013, 2016; Rowe, 1994). Yet, a discussion of this topic is needed, because often in educational, psychological, and neuroscience research SES is treated as a causal influence rather than a hypothesized causal determinant that needs to be examined in the context of other purported causes (Gottfresdon, 2004; Lubinski, 2009b). The tendency to conflate causality with the many correlations manifested by SES has a long history (Meehl, 1970, 1971), and has been dubbed the *sociologist's fallacy* (Jensen, 1973). One illustrative example for the importance of examining the potential of both (IQ/SES) sources, simultaneously, is especially germane to this review -- namely, the physical-medical health status of intellectually talented participants.

Although Terman's (1925) intellectually talented sample was indeed healthier relative to the norm both physically and psychologically, these participants also resided in homes approximately 1 standard deviation above the norm in SES (and experienced more privileged conditions). So causal attribution remained equivocal: Was their physical and psychological well-being a function of their ability or their economic advantage? To address this question empirically, the following large-scale study was conducted.

Using the stratified random sample of the U.S. 10th grade student population in Project Talent (Flanagan et al., 1962), N = 95,650 participants, Lubinski and Humphreys (1992) selected the top 1% on a measure of cognitive ability, for each sex, as well as the top 1% on a measure of SES. The four resulting groups, gifted boys n = 497, gifted girls n = 508, environmentally privileged boys n = 647, environmentally privileged girls n = 485, had minimum overlap (under 5%). Only 41 boys and 46 girls were members of both the privileged and gifted groups. For analytic purposes, these gifted and privileged participants were simply left in each group. Next, their medical and physical well-being profiles were compared by sex to each other and, correspondingly, to the full sample of Project Talent participants, on 43 indices of medical and physical health and well-being.

To underscore the gifted/privilege comparisons being made, the two intellectually gifted groups were 2.7 standard deviations above the norm on cognitive ability and 1.1 standard deviations above the norm on SES; whereas the environmentally privileged participants were 2.3 (boys) and 2.5 (girls) standard deviations above the norm on SES, and 1.0 standard deviations above the norm in cognitive ability. Intellectually, the highly privileged participants were closer to the norm than they were to the gifted participants; while with respect to SES, the gifted participants were closer to the norm than they were to the privileged participants. In essence, Lubinski and Humphreys (1992) found above average levels of health for both the gifted and the privileged groups. Further, medical and physical well-being was more highly associated with extreme levels of intellectual giftedness than extreme levels of SES privilege. The intellectually gifted participants were medically and physically healthier than the privileged participants, even though the gifted were reared in homes more than 1 standard deviation *below* the privileged groups in SES.

These findings are important to detail, because there is a dominant tendency to associate causal significance to SES relative to cognitive ability in conceptualizing a variety of important outcomes across the biosocial sciences (Bouchard, 2009; Deary et al., 2005; Lubinski, 2009b; Murray, 1998). Indeed, cognitive ability is frequently not considered when modeling healthy behaviors and outcomes. However, Gottfredson (2004) offers a compelling analysis that cognitive ability is a more dominant covariate than SES, not only because of biological antecedents to more optimal biomedical functioning, but also because of more optimal problem solving capability in the utilization of health care information (e.g., holding SES constant within families). This also explains why the health-SES gradient extends throughout the full SES spectrum. While the influence of SES on key social science outcomes should clearly not be dismissed, these and many other findings highlight the need to assess cognitive abilities simultaneously with ongoing empirical research on the causal force of SES. As the philosopher Susan Oyama (2000) has stressed, we must develop a “causal democracy” in developmental systems theory. Especially powerful procedures are available for more cleanly untangling ability/SES (Jensen, 1980b). Among the most powerful is the “sibling control” (Murray, 1998, 2002), which untangles ability/SES causal paths through a within family design in an especially clean and compelling way. This is an important topic, worthy of a review of its own (cf. Bouchard, 2009; Meehl, 1986, 1989).

SUPPLEMENTAL NOTE 2

Aptitude versus Achievement Tests

Attendant throughout this discussion was the question of the extent to which wide-ranging achievement tests, when aggregated to form a measure of general educational knowledge, index general intellectual ability. That “achievement” and “aptitude” measures refer to differences in degree, rather than kind, has been known for years [Cleary et al.’s (1975) APA Task Force Report]. One label is more likely to be used over the other as a function of the tool’s status across four dimensions: breadth of item sampling, recency of learning, the extent to which content reflects a particular educational curriculum, and the purpose of assessment (current status versus forecasts about development). Just as building measures by systematically sampling heterogeneous collections of more focused symbolic content or specific abilities distills a general intellectual dimension, doing so within similar cultures accomplishes the same when achievement (crystallized) measures are aggregated as long as sampling is wide (Rosnowski, 1987). It was this phenomenon that Kelley (1927) actually cited when he introduced the *Jangle Fallacy*.

> Equally contaminating to clear thinking is the use of two separate words or expressions covering in fact the same basic situation, but sounding different, as though they were in truth different. The doing of this … the writer would call the “jangle” fallacy. “Achievement” and ‘intelligence” … We can mentally conceive of individuals differing in these two traits, and we can occasionally actually find such by using the best of our instruments of mental measurement, but to classify all members of a single school grade upon the basis of their difference in these two traits is sheer absurdity (Kelley, 1927, p. 64).

Cronbach (1976) also pointed to this phenomenon in responding to critics of psychological testing:

> *In public controversies about tests, disputants have failed to recognize that virtually every bit of evidence obtained with IQs would be approximately duplicated if the same study were carried out with a comprehensive measure of achievement.* (Cronbach, 1976, p. 211, italics original)

That aggregated achievement measures engender external correlates mirroring those for IQ over a variety of important purposes is a good lens through which to view Learned and Wood's (1938) "*The Student and His Knowledge*." In many instances, they afford similar information for general purposes. To be clear, specific abilities and knowledge domains add critical information about unique strengths and relative weaknesses, thus facilitating optimal research and practice. However, for global first approximations, comprehensive measures of achievement and IQ routinely reflect similar starting points (Bartholomew, 2004). Indeed, Terman (1925, p. 306) concluded his chapter on Tests of School Accomplishment and of General Information, which showed these assessments to distinguish his participants from the norm as well as measures of general intelligence: "The general information test described in this chapter is an excellent test for use in the identification of gifted children."

SUPPLEMENTAL NOTE 3

Appropriate Developmental Placement and Item Response Theory (IRT)

Although it is typically not conceptualized in this way, the gifted field has neglected to draw support for acceleration from longstanding advances in modern measurement procedures (Embretson & Reise, 2000). Doing so leverages psychological justification for the importance of appropriate developmental placement in general and acceleration for students with intellectual precocity in particular. Just as item response theory (IRT) has revealed the importance of assessing students only with items within their "effective range of measurement," namely, the range between each student's basal level and the point at which they respond with chance probability (ceiling level), the same idea may be generalized to educational curricula. That is, for any given domain, there will be content that each student already knows (which should be disregarded for instruction), and content for which each student is not yet ready (which should be avoid until later stages of development). For optimal instruction, the content of instruction should focus on the range between these two extremes. One could say that implementing appropriate developmental placement restricts instruction to within basal-ceiling endpoint extremes; or, to coin a term, the "effective range of instruction." Presenting curricula outside this range constitutes *dysfunctional instruction*.

SUPPLEMENTAL NOTE 4

Where are Students with Intellectual Precocity Found?

Because socioeconomic status is frequently conflated with individual differences in general intellectual ability (Sackett et al., 2009), a national probability sample of the correlation between general intelligence and SES ($r \approx .40$) is included here. In "A conceptualization of intellectual giftedness," Humphreys (1985) constructed the table below to highlight why in searching for intellectual talent one needs to cast a wide net. Here, based on a sample drawn from Project TALENT of 44,423 ninth grade boys, their general intellectual ability was divided into nine categories and their SES was parsed into seven categories to form a scatter plot. The preponderance of the top-tier of intellectual talent is found in the SES slice just above the center of the distribution ("5"), and the proportion below SES level 5 contains almost 70% of the top tier of intellectual talent relative to tiers' above level 5. Humphreys leveraged these findings to stress that if educational opportunity were more a function of intellectual ability relative to SES, social modality would be 33% more fluid than it currently is (see also Bereiter, 1976; Kuncel & Hezlett, 2010).

Socioeconomic Status; From Lowest Level (1) to Highest Level (7)

Intelligence From the Lowest Level (1) to the Highest Level (9)	1	2	3	4	5	6	7	Total
9		*	0010	0066	0136	0102	0012	0326
8		0005	0056	0251	0373	0226	0025	0936
7	*	0021	0149	0498	0554	0232	0022	1476
6	0002	0044	0273	0655	0582	0196	0014	1766
5	0007	0090	0402	0728	0511	0121	0009	1868
4	0010	0133	0476	0683	0376	0072	0006	1756
3	0013	0155	0409	0488	0240	0046	0003	1354
2	0007	0060	0146	0159	0078	0014	0001	0465
1	*	0005	0015	0018	0013	0002		0053
Total	0039	0513	1936	3546	2863	1011	0092	1.000

Scatterplot in Relative Frequencies of Intelligence and Socioeconomic Status for a Sample of 9th-Grade Boys, *N* = 44,423

*Nonzero frequency, but less than .00005. Decimal points have been omitted elsewhere.
Note. This table reveals the relative frequency with which the 63 possible combinations of SES and intelligence occurred in the sample of more than 40,000 ninth-grade boys. Only three combinations had zero frequencies. One can note, for example, that only .0012 out of a total of .0326 at the highest level of intelligence were from the highest level of SES. The families at this level of SES contributed only a little more than 3 percent of the most intelligent children. Based on data from Project Talent, cited in Flanagan et al. (1962). Reproduced from Humphreys (1985).

SUPPLEMENTAL NOTE 5

Identifying, Developing, and Modeling STEM Talent

In 1957, when Super and Bachrach (1957) issued the Scientific Careers NSF Report, and even within the more extensive Project TALENT (Flanagan et al., 1962), there were not sufficient numbers of graduate student women in STEM to draw reliable psychological profiles of the abilities, interests, values, and experiences for females in world class STEM careers -- opportunities for women were simply too limited at that time. Things have changed (Ceci et al., 2014; Ceci & Williams, 2011). Modern studies have revealed similar profiles of abilities/interests/values and experiences of world class STEM graduate students across both sexes (Lubinski, Benbow, Shea, Eftekhari-Sanjani, & Halvorson, 2001). As the data reviewed thus far reveal, and in particular for inorganic STEM disciplines, contributors are characterized by exceptional mathematical/spatial abilities and regnant scientific (relative to other) interests. Thus, major progress has been made on the sketch Terman (1954b) offered at the end of his extensive analysis of scientists versus nonscientists among his participants: What is now called for, "… instead of a single group of subjects representing the generality of children with high IQs, two gifted groups closely matched for superior IQs but otherwise unlike as possible with respect to scientific promise. The selection of the two contrasting groups would need to be based largely on batteries of tests and ratings of special abilities and interests believed to be symptomatic of scientific talent" (Terman, 1954b, p. 40). Yet, going beyond this, the modern literature holds additional refinements for the scientific study of STEM talent. They too draw on broader issues in the social sciences such as the *criterion problem* and the *development of expertise*.

The Criterion Problem. Today, large expenditures are being devoted to the development of STEM talent (National Academy of Sciences, 2005; National Science Board, 2010), and for good reason. STEM innovation drives modern economies (Hunt & Wittmann, 2008; National Science Board, 2010; Rinderman & Thompson, 2011). However, there are huge differences in the outcomes needed to examine procedures designed to enhance STEM literacy, STEM competence, STEM expertise, and genuine STEM innovation. All of these outcomes are important. Yet, they are often conflated in psychoeducational research. To be sure, the public needs to be STEM literate to make informed decisions about climate change and whether evolution should be taught in K-12 schools. The procedures needed to foster broad-spectrum (populace) development are quite different from the procedures needed to identify the kind of talent, commitment, and opportunities required for genuinely advancing STEM disciplines. Procedures focused on the former are akin to readers of this article consulting health care professionals about an optimal diet and exercise plan; procedures aiming for the latter are more akin to training for the Olympics.

In Figure 4, of the over 2,400 intellectually precocious participants studied over 25 years (Park et al., 2007), 18 ultimately secured tenure at a top 50 U.S. university in a STEM discipline – a modest albeit meaningful criterion for intellectual leadership in STEM. For these 18 participants, their mean SAT-M score before age 13 was 697, and the lowest SAT-M score was 580 (the 60^{th} percentile of the top 1%). (This mean is actually an underestimate, because two participants earned top possible SAT-M scores of 800 prior to age 13, and others were close.) The age-12 SAT-V score for this group was 534, reflecting the characteristic mathematical/verbal "tilt" (even though a SAT-V of 430 marks the cut for the top 0.5%). This underscores the general and mathematical reasoning capability of world-class STEM innovators, which is supported by other real-world examples cross culturally. See, for example, the selection procedures Bill Gates used to build his Research-Institute-Beijing (Friedman, 2007, pp. 367-368), or those used to select students in India's Institute of Technology (Zakaria, 2011, pp. 205-206).

While criterion level is important for evaluating differential accomplishments in STEM outcomes, different criterion qualities are needed for obtaining a more comprehensive understanding. Figure 6, for example, organized creative criterion outcomes for profoundly gifted participants. Their age 12 mathematical and verbal reasoning assessments found in the Figure 5 scatter plots reveal that essentially all participants possess more mathematical talent than the typical STEM PhD (cf. Figure 2). Yet, utilizing a diversity of criterion outcomes shows that among students with profound mathematical gifts, those who are even more able verbally are likely to pursue learning and work opportunities outside of STEM disciplines. A heterogeneous collection of rare outcome criteria needs to be assembled to capture these phenomena and provide psychological understanding. Such considerations likely have a bearing on educationally efficacious interventions designed to select prospective STEM professionals and innovators as well as the outcomes utilized when evaluating interventions designed to enhance specific cognitive abilities. For example, that cognitive abilities can be enhanced is clear (Robinson et al., 1996, 1997; Uttal et al., 2012), but whether modest gains among individuals with marked intra-individual differences in intellectual profiles will change the course of ultimate development is a different matter (Kell et al., 2013a; Makel et al., 2016).

Knowledge Decay. Economists have discussed the importance of "knowledge decay" (Golden, 2014; McDowell, 1982). Disciplines and occupations differ widely in terms of how much continuous updating is needed to stay current. While all modern disciplines and professions face this to varying degrees, some occupations are more demanding than others, and STEM careers are among the most challenging in this regard. One reason why it is difficult to check out of and re-enter STEM disciplines is because knowledge and technical updating are part of its continuous fabric. STEM environments are occupied by an inordinate number of individuals who assimilate abstract mathematical/spatial material at rapid rates (Figure 2); this is what is needed to stay relevant, but it is essential to staying cutting edge. To maintain state-of-the-art skill sets requires engagement with one's craft. Decay is rapid when disengagement occurs over protracted intervals within disciplines known for rapid knowledge growth. The gifted field and the psychoeducational community could draw on this aspect of the modern world of work to a greater degree when conceptualizing differential outcomes. Knowledge decay is another variable that underscores why time is a critical variable that must be considered when modeling phenomena in educational and occupational settings (Anderson, 1984, 1985; Carroll, 1989). While STEM is not unique from a number of other disciplines and professions in terms of knowledge decay, it is likely quantitatively different from many in this respect.

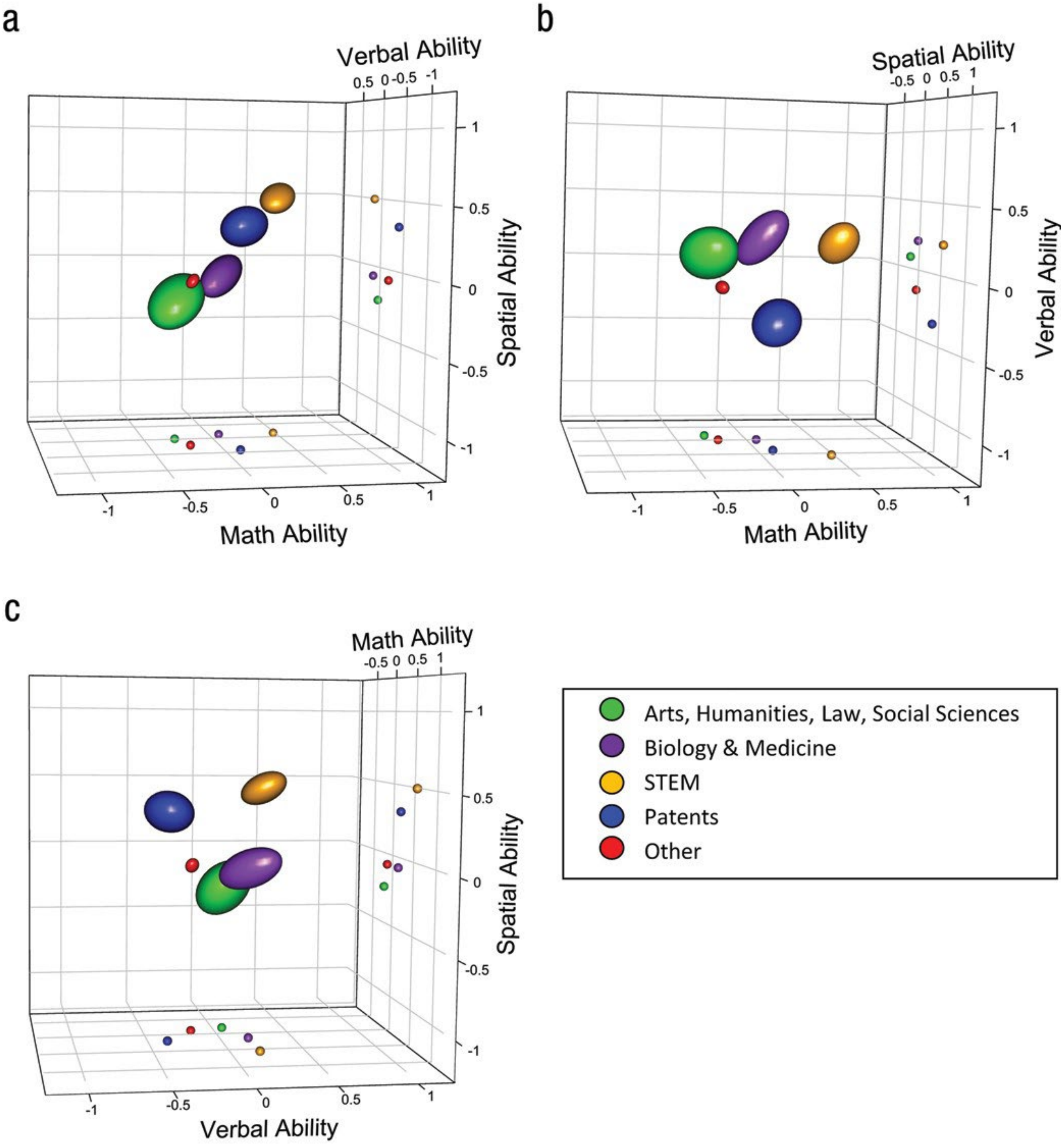

Figure S1a-1c. Confidence ellipsoids showing the locations of the four criterion groups in the three-dimensional space defined by scores for mathematical, verbal, and spatial reasoning ability. The data are rotated such that the graph in (a) shows mathematical ability on the x-axis, spatial ability on the y-axis, and verbal ability on the z-axis; the graph in (b) shows mathematical ability on the x-axis, verbal ability on the y-axis, and spatial ability on the z-axis; and the graph in (c) shows verbal ability on the x-axis, spatial ability on the y-axis, and mathematical ability on the z-axis. The ellipsoids are scaled so that each semiprincipal axis is approximately equal in length to the standard error of the corresponding principal component. Each ellipsoid is centered on the trivariate mean (centroid), and bivariate means are plotted on the bordering grids. The criterion groups were defined as participants with a refereed publication in the arts, humanities, law, or social sciences; a refereed publication in biology or medicine; a refereed publication in science, technology, engineering, or mathematics (STEM); or a patent. In addition, an ellipsoid is shown for participants with none of these creative accomplishments (“other”). From Kell, Lubinski, Benbow et al. (2013).

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