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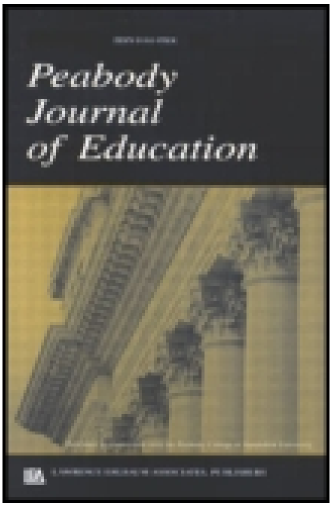

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Identifying and Nurturing Future Innovators in Science, Technology, Engineering, and Mathematics: A Review of Findings From the Study of Mathematically Precocious Youth

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Identifying and Nurturing Future Innovators in Science, Technology, Engineering, and Mathematics: A Review of Findings From the Study of Mathematically Precocious Youth

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Calls to strengthen education in science, technology, engineering, and mathematics (STEM) are underscored by employment trends and the importance of STEM innovation for the economy. The Study of Mathematically Precocious Youth (SMPY) has been tracking over 5,000 talented individuals longitudinally for 40 years, throwing light on critical questions in talent identification and development in STEM. SMPY includes individuals identified in 7th/8th grade as in the top 1% or higher in mathematical or verbal ability, and a comparison group identified as top STEM graduate students. SMPY findings cover the educational and occupational attainments of participants, including a large percentage earning a degree or pursuing high powered careers in STEM; gender differences; the extent to which high school experiences, abilities, and interests predict later outcomes; and subsequent creative production. Mathematical reasoning ability as measured by standardized tests is a reliable predictor for later math/science engagement and achievement in adulthood, and spatial ability adds predictive value. Exposure to appropriate educational opportunities do correlate with career achievement and creative production. SMPY researchers have concluded that potential future STEM innovators can be identified early and that educational interventions can increase their chances of success.

In April 2011, a group of 110 business executives, including the former CEO of Intel, issued a call for states to adopt tougher standards on math and science tests. The group, Change the Equation, also encouraged states to address gaps in achievement among different racial groups (Koebler, 2011). Change the Equation's call to action closely followed the release of *The Case for Being Bold* by the Institute for a Competitive Workforce (ICW; Hess, Kelly, & Meeks, 2011). In its report, ICW, which is affiliated with the U.S. Chamber of Commerce, outlined strategies for business to use its resources and political clout to engage more intensively with science, technology, engineering, and mathematics (STEM[1]) education.

This article is an elaboration of a speech given at the National Academies of Science Behavioral Research Committee Meeting, December 2009, and thus draws upon already published material. Some of the findings were previously presented in Halpern et al. (2007).

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[1] Other authors in this issue of the *Peabody Journal of Education* opt to use the acronym STEMM to indicate the inclusion of medical fields. We prefer the more commonly understood STEM and believe it to be inclusive of medicine among the sciences.

Efforts by these and similar groups continue more than half a century of activity by both the private sector and government to strengthen STEM education and improve U.S. economic competitiveness. In his State of the Union Address in January 2011, President Barack Obama said, "Over the next 10 years, with so many baby boomers retiring from our classrooms, we want to prepare 100,000 new teachers in the fields of science and technology and engineering and math" (The White House, 2011). Organizations like the Carnegie Corporation of New York have stepped forward to try to help the president deliver on this promise (see http://100kin10.org/).

There is reason to hope for a robust STEM education system. According to a recent report from the U.S. Department of Commerce, from 2000 to 2010, STEM employment in the United States grew at three times the rate of non-STEM jobs. The Department of Commerce projects growth in STEM jobs to outpace growth in non-STEM jobs until at least 2018. In addition to the expanding field, STEM workers on average earn 26% more than non-STEM workers, and they are less likely to experience unemployment (Langdon, McKittrick, Beede, Khan, & Doms, 2011).

With business and government both committed, and potentially 100,000 new STEM teachers in the pipeline, it becomes important to answer the question of where our future STEM innovators are located. Once identified, we must then decide what we need to do to nurture their talents and bring them to their fullest maturity. In its 2010 report, *Preparing the Next Generation of STEM Innovators: Identifying and Developing our Nation's Human Capital*, the National Science Board made three keystone recommendations and suggested multiple accompanying policy actions in an effort to answer these questions. Its broad recommendations were to "provide opportunities for excellence," "cast a wide net," and "foster a supportive ecosystem" (National Science Board, 2010). By reviewing the history and research findings of the Study of Mathematically Precocious Youth (SMPY), we hope to throw further light on the twin challenges of talent identification and talent development.

SMPY

The SMPY is one of the earliest attempts to answer questions like those just presented. Julian C. Stanley, of Johns Hopkins University, founded the study in 1971. Now directed by Camilla Persson Benbow and David Lubinski, SMPY has been tracking more than 5,000 individuals, in five cohorts, for more than four decades, with a particular focus on mathematical talent. Planning at least a 50-year study, the SMPY is currently collecting data on participants at age 50, an age that many believe provides a first but strong glimpse of participants' professional accomplishments.

Design of SMPY

Although a detailed description of the SMPY longitudinal study can be found in Lubinski and Benbow (2006), here we provide a brief description. SMPY's first cohort contained seventh or eighth graders (or students of approximately 13 years of age) from the greater Baltimore area. Identified as intellectually talented in the early 1970s, this cohort represents the top 1% in mathematical ability. The second cohort comprised seventh graders from the Mid-Atlantic region who had scored in the top .5% in mathematics or verbal ability, or both. The third cohort included those from across the nation who were identified in the early 1980s, and before age 13, as being in the top 1 in 10,000 in math, verbal, or both abilities. The fourth cohort, drawn from the Midwest in the late 1980s and early to mid-1990s, represents the top .5% in ability in math, verbal, or both as determined in the seventh or eighth grade. The fourth cohort included a comparison group of less able individuals but nonetheless in the top 5%. In all, there were more than 5,000 individuals in Cohorts 1 to 4 who were identified using the College Board's Scholastic Aptitude Test (SAT), now called the Scholastic Assessment Test. Although the SAT is normally administered to high school juniors or seniors, SMPY administered the tests to individuals 4 to 5 years younger in age and selected for further study those meeting the ability criteria just described. For these 13-year-olds, the SAT is an especially strong measure of mathematical or verbal reasoning ability. The test has demonstrated both reliability and validity with this younger population. Collectively they possessed the potential, when identified by age 13, for high, even extraordinary, achievement, in math or the sciences (Lubinski & Benbow, 2006).

At multiple points, the SMPY participants have completed comprehensive surveys and inventories that provide a detailed view of their development and educational or career trajectories. Although earlier data collection points occurred at ages 13, 18, and 23, the last administered survey took place when participants were in their mid-30s. As indicated, the next survey has begun with participants at age 50. Because all groups were identified using the SAT at about the same age, researchers have used data from later cohorts to determine the replicability of their findings. Replicability is a powerful aspect of the study, and some SMPY studies do not reach publication until findings have been confirmed with another cohort. Another benefit of having multiple cohorts separated in ages is that it allows SMPY to roughly assess the impact of having grown up in different times.

In practical terms, not all future STEM talent can be identified using the SAT at age 13. SMPY's fifth cohort was therefore established to determine whether the study's findings are generalizable. Cohort 5 consists of 714 individuals, educated in the United States, who were enrolled in the top 15 U.S. graduate programs in STEM. Although this is an extremely high level of achievement in STEM for the approximate ages of 23 to 24, it still produced sufficiently large numbers of individuals for quantitative analysis. In an effort to maintain an equal sample of male and female students, women had to be oversampled as the male:female ratios in these graduate departments often exceeded 3:1. Cohort 5 was studied retrospectively, concurrently, and now prospectively (age 33 and beyond) by Lubinski, Benbow, Shea, Eftekhari-Sanjani, and Halvorson (2001) and Lubinski, Benbow, Webb, and Bleske-Rechek (2006).

THEORY OF WORK ADJUSTMENT

The Theory of Work Adjustment guides SMPY's work (Dawis & Lofquist, 1984). As described by Lubinski and Benbow (2000, 2006) and paraphrased here, Theory of Work Adjustment assesses both the individuals and their environments equally. The study splits the individual's learning or work personality into two major components—abilities and preferences (interests and values)—while splitting their environment into ability requirements (for meeting performance expectations) and incentives (for acknowledging and compensating performance). Large individual differences in capability result in important outcome differences in education and the world of work (Lubinski, 2000).

According to Theory of Work Adjustment, educational commitment, occupational choice, and persistence are functions of two major dimensions of correspondence: *satisfaction* (correspondence between needs and rewards) and *satisfactoriness* (correspondence between ability and ability requirements). Satisfaction is a subjective determination made by individuals, whereas satisfactoriness is determined objectively by educators and supervisors based on performance. Satisfaction determines whether and how much an individual is motivated to remain in a particular environment, whereas satisfactoriness determines how motivated employers may be to retain an employee. Both satisfaction and satisfactoriness must be present for individuals to remain in educational or occupational settings.

MATHEMATICAL TALENT AND STEM INNOVATION

SMPY data have already yielded valuable information about how potential, as measured by the SAT, translates into achievement in math/science. The data also offer insights into who, among those with the requisite abilities to become STEM professionals or STEM innovators, embarks upon such career paths in the first place.

Individuals in the top 1% in mathematical reasoning ability, as assessed by age 13, did become highly educated. More than 90% earned a bachelor's degree, whereas more than 25% earned a doctorate, with essentially no gender differences in degrees earned (Benbow, Lubinski, Shea, & Eftekhari-Sanjani, 2000). About 50% earned at least one postsecondary degree in the STEM areas. Among the top .5% in mathematical ability, 64% secured at least one postsecondary math or science degree (Benbow et al., 2000). Men were at least twice as likely as women to earn degrees in the inorganic sciences and engineering. At the doctoral level, there were almost 5 times as many male as female students. Yet, in the life sciences and in medicine, there were more women than men, including at the doctoral level (Benbow et al., 2000). The career choices of these mathematically talented individuals followed the pattern seen for degree specialization. Men were more heavily represented in mathematics, computer science, engineering, and the physical sciences, whereas women were somewhat more represented in the life sciences and medicine (Benbow et al., 2000).

SMPY also studied those mathematically talented individuals who had planned to major in a STEM area as beginning undergraduates at more depth at approximately age 33. We wanted to better understand the factors that differentiated those who remained in the math-sciences and earned such a degree from those who opted to pursue undergraduate degrees in other areas (Webb, Lubinski, & Benbow, 2002). More men had declared an intention to pursue a STEM degree than had women; there was also greater attrition from the math and sciences by women than by men (26% vs. 17%). High school educational experiences, abilities, and interests were found to predict whether an undergraduate degree was indeed attained within the math and sciences or whether the individual left to pursue other areas of study. Those who persisted with a math or science degree had more high school coursework in mathematics and science, and more often reported a math or science course as their favorite (or a humanities course as their least favorite). They were also more mathematically able, and their occupational interests as measured by the

Study of Values and Holland Occupational codes were more congruent with math and science professions.

The Webb et al. (2002) study probed further the educational and occupational outcomes of those individuals who left the math and science field sometime during their undergraduate years. Although those who left did so primarily for reasons involving interests, they nonetheless went on to earn educational credentials comparable to those who remained in STEM areas and pursued similarly prestigious occupations. Somewhat surprisingly, 17% subsequently returned to the math and sciences field, calling into question the commonly held assumption that once one leaves the math and science pipeline, it is very hard to return.

SMPY also compared math and science achievement between the top and bottom quartiles of the top 1% in mathematical reasoning ability at age 13 (Benbow, 1992; Wai, Lubinski, & Benbow, 2005). Of 37 math and science achievement variables assessed at age 23, we found statistically and substantively significant effect sizes favoring the top versus the bottom quartile on 34 of the 37 variables (Benbow, 1992). Gender differences were found, but these were smaller than the differences between the top and bottom quartiles. We did not observe gender differences in the relationship between mathematical ability and academic achievement. The same pattern was observed at age 33 when we studied secured doctorates, math and science Ph.D's, income, patents, and tenure-track positions at top U.S. universities (Wai et al., 2005).

In subsequent studies, Park, Lubinski, and Benbow (2007, 2008) looked at creative production when SMPY participants were in their mid-40s. Searching Google Scholar, web pages, and the U.S. patent database, researchers determined that higher creative production was associated with higher ability as measured by the SAT at age 13. This occurred regardless of the graduate school attended.

Collectively, the studies just discussed and Ferriman-Robertson, Smeets, Lubinski, and Benbow (2010) rendered false the assertions made by such writers as Malcolm Gladwell (2008) in *Outliers,* Renzulli (1986), Brooks (2011), and the authors of a letter published in *Science* (Muller et al., 2005), who claimed, "There is little evidence that those scoring at the top of the range in standardized tests are likely to have more successful careers in the sciences. Too many other factors are involved" (p. 1043). SMPY has repeatedly found that more ability, especially in mathematics, does matter for achievement in STEM. When coupled with a congruent preference pattern, ability becomes an even better predictor of both the discipline in which one is likely to earn a 4-year degree (Achter, Lubinski, Benbow, & Eftekhari-Sanjani, 1999) and one's future occupational setting at age 33 (Wai et al., 2005).

These findings are all based on participants in Cohorts 1 to 4, but they needed to be replicated with a different sample. To do this, SMPY turned to Cohort 5 (the 714 graduate students enrolled in the top 15 math-science graduate programs). Like the previous cohorts, these students had world-class talent as well as psychological profiles that corresponded to what earlier studies had found to characterize distinguished scientists: exceptional quantitative reasoning abilities (the modal GRE-Q score was 800), relatively stronger quantitative than verbal reasoning ability, salient scientific interests and values, and persistence beginning at an early age in seeking out opportunities to study scientific topics and develop scientific skills (Lubinski et al., 2001). As in areas such as athletics and arts, the process of developing scientific talent had begun and was sustained as early as the fifth grade. For those graduate students with these attributes, sex differences were minimal. SMPY researchers concluded that exceptional scientific expertise requires special educational experiences and personal characteristics and that these necessary experiences and characteristics operate similarly for both men and women. Researchers also determined that the earlier findings on the SMPY sample generalized to another group (i.e., Cohort 5) selected using entirely different criteria on the basis of their potential to pursue scientific careers.

The graduate students in Cohort 5 were followed up on 10 years later when they were in their mid-30s and compared to a SMPY group of similar age who had achieved scores prior to age 13 that placed them in the top 1 in 10,000 in cognitive ability (verbal or mathematical; Lubinski et al., 2006). The latter group had been selected solely on the basis of this exceptionally high test score. Both groups were found to have achieved comparable and exceptional success, and they both reported high and commensurate career and life satisfaction. Almost 80% of the graduate students had indeed earned a doctorate, whereas 55% of the high-ability group had. (The base rate for earning a doctorate in the United States is 1%.) Almost 70% of the graduate students were postsecondary teachers, engineers, or scientists compared to 46% of the high-ability group. (Given the selection criterion, it was remarkable that the differences were not larger on these variables.) In terms of patents secured, an indicator of creativity and "inventive and scientific productivity" (Huber, 1999, p. 49), all groups exceeded base rate expectations of 1% for the U.S. population. Thirty-two percent of male graduate students and 21% of female graduate students had earned patents, compared to 18% and 4%, respectively, in the high-ability group. Data also showed that the necessary attributes for high achievement in STEM areas, and the talent development process itself, do not change depending on gender. Different variables are not needed to explain the scientific success of women in comparison to men. The relevant variables, however, do need to be examined collectively and not in isolation.

Collectively, the studies just described speak to the effectiveness of mathematical reasoning ability as a predictor for later math/science achievement. Prediction can be further refined when spatial ability is considered, especially if one considers the relative strength of mathematical ability compared to verbal ability (profile tilt). Such distinctions in intellectual strengths, even when observed at an early age, can predict sharp differences in how individuals will develop and which occupations they will pursue (Achter et al., 1999; Lubinski, Webb, Morelock, & Benbow, 2001).

SPATIAL ABILITY AND OCCUPATIONAL CHOICE

Along with mathematical and verbal ability, spatial ability is the third major specific ability in the structure and organization of human abilities (Carroll, 1993; Snow & Lohman, 1989). Engineering, architecture, physics, chemistry, and medical surgery are occupations long associated with a proficiency in spatial ability (Smith, 1964; Snow & Yalow, 1982). Spatial ability is also a salient characteristic of physical scientists (Gohm, Humphreys, & Yao, 1998; Humphreys, Lubinski, & Yao, 1993). Schools, however, do not assess spatial ability with any frequency, nor is the presence or lack of spatial ability used much to counsel students. According to the 13-year longitudinal study conducted by Humphreys et al. (1993) of 400,000 high school students assessed on mathematical, verbal, and spatial abilities, STEM disciplines appear to be losing many talented individuals because selection for such educational tracks is limited only to mathematical and verbal abilities. Wai, Lubinski, and Benbow (2009) arrived at the same conclusion when reviewing 50 years of data on spatial ability.

Yet spatial ability manifests its importance whether or not the educational system accounts for it. Shea, Lubinski, and Benbow (2001) applied multivariate statistical methods, using age

13 SAT math (SAT-M), SAT verbal (SAT-V), and a spatial ability composite for top .5% in ability individuals, to predict developmentally sequenced educational and vocational outcomes including (a) favorite and least favorite high school course, (b) field of undergraduate degree, (c) field of graduate degree, and (d) occupation at age 33. Spatial ability was found to add incremental validity to SAT-M and SAT-V assessments in predicting educational and vocational outcomes over 20 years. Intellectually talented adolescents with stronger spatial ability relative to verbal ability were more likely to be found in engineering and computer science fields. Those with the inverse ability pattern tended to gravitate toward humanities, social science, organic science, medical arts, and legal fields. A similar pattern also emerged for relative strengths in quantitative versus verbal abilities, with spatial ability exhibiting somewhat greater overall discriminative power. That is, students who were relatively more verbally able than quantitatively or spatially able gravitated toward the humanities and social sciences, whereas those with the opposite ability pattern leaned more toward engineering and the physical sciences. Webb, Lubinski, and Benbow (2007) obtained similar results with an independent sample of 1,060 high-ability adolescents tracked for 5 years.

Lubinski et al. (2001) conducted a more definitive study with a sample of exceptional high-ability (top 1 in 10,000) individuals and found that those whose strength was in mathematics compared to verbal, but who nonetheless had very high verbal ability, reported mathematics and science courses as their favorite in high school and college. This group also disproportionally pursued educational credentials in STEM areas, reporting 3 times as many awards and special accomplishments in science and technology as compared to the humanities and arts. Those whose ability pattern favored verbal over mathematic ability reported favorite courses in humanities in high school and college, disproportionately pursued educational credentials in the humanities and law, and reported twice as many awards and special accomplishments in the humanities and arts compared to sciences and technology. Those with profiles of relatively equal verbal and mathematical ability fell somewhere in between. Because this sample of profoundly gifted participants possessed higher quantitative reasoning abilities than the typical physical scientist, the ability tilts were seen as especially revealing. The investigators concluded, with confidence, that the tilt in the ability profile predicts the nature of achievement years later.

Some gender differences in ability tilts must be acknowledged—men more frequently than women, exhibited a tilt favoring mathematical and spatial ability over verbal ability, regardless of level. Women, on the other hand, tend to be more balanced than men in their ability profiles. This may also relate to their less frequent choice of STEM careers than their male counterparts.

LIFESTYLE PREFERENCES AND STEM INNOVATION

Occupational choices are not made in isolation or independent of other life decisions, such as the decision to marry, to have children, or to live close to relatives (Eccles, 1994). Many high-achieving women experience conflict between traditionally feminine values and goals (e.g., caring for children) and the expectations of traditionally masculine activities oriented toward high achievement and competition (Browne, 2002; Eccles, 1994). Intellectually talented men in their mid-30s tend, on average, to focus more on career, to work longer hours, and to be willing to work longer hours than similarly talented women who report a preference for a life with a balanced approach to career, family, and friends (Benbow et al., 2000; Ferriman, Lubinski,

& Benbow, 2009; Lubinski, 2004; Webb et al., 2002). Sustained over time, such preferences may help explain the current underrepresentation of women in high levels of science (Eccles, 1994). Men in the SMPY sample reported higher incomes, but that difference disappeared when researchers adjusted the study for hours worked. It must also be emphasized that, on all indicators examined, talented men and women in their mid-30s reported feeling equally positive about themselves and their accomplishments.

Although the aforementioned studies clearly indicate that we can identify talent as early as age 13, and that this is the pool of individuals from which future STEM innovators will emerge, they do not tell us whether we can increase the likelihood of developing this talent to the point of fruition. Wai, Lubinski, Benbow, and Steiger (2010) presented data revealing that this is, in fact, possible. Wai et al. (2010) introduced the concept of educational dose, which is a way of describing the educational facilitation and intervention that talented individuals receive during their schooling. Some talented individuals are fortunate and attend schools highly responsive to their exceptional educational needs (they receive a high educational dose), whereas other individuals will languish in the regular classroom without any modifications to the curriculum (receiving a low educational dose). By age 40, Wai et al. found that those who experienced a high educational dose achieved more than those with no or a low dose.

Greg Park, as part of his dissertation, compared students who were accelerated by at least a year with students who were not accelerated (Park, Lubinski, & Benbow, 2011). The two groups were matched on a dozen relevant variables. Park found that those who were accelerated had achieved more career-wise with more creative production by their mid-40s than had those who were not accelerated. Given the sophistication and extent of the matching procedure, acceleration had to be the most likely cause for the differences in achievement. Numerous other studies have come to the same conclusion (e.g., Rogers, 2007; Swiatek & Benbow, 1991a, 1991b). However, the other studies were less rigorously designed than Park et al. (2011). This supports the National Mathematics Advisory Panel's (2008) conclusion that, as a policy, acceleration should be a means for meeting the expressed needs of mathematically talented students.

CONCLUSION

We began this article by asking whether we can identify individuals early on who are likely to become STEM innovators, and whether, once identified, we can increase the chances they will become STEM innovators—a phenomenon that is extremely rare. Based on the data and findings presented in this review, the answer to both of these questions is yes. Schools can increase their ability to produce future STEM innovators for our conceptual economy through proper identification procedures followed by educational interventions that are responsive to children's needs. Doing so has the potential to provide an economic edge in an increasingly competitive global society.

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