Research Report

Ability Differences Among People Who Have Commensurate Degrees Matter for Scientific Creativity

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ABSTRACT—*A sample of 1,586 intellectually talented adolescents (top 1%) were assessed on the math portion of the SAT by age 13 and tracked for more than 25 years. Patents and scientific publications were used as criteria for scientific and technological accomplishment. Participants were categorized according to whether their terminal degree was a bachelor's, master's, or doctorate degree, and within these degree groupings, the proportion of participants with at least one patent or scientific publication in adulthood increased as a function of this early SAT assessment. Information about individual differences in cognitive ability (even when measured in early adolescence) can predict differential creative potential in science and technology within populations that have advanced educational degrees.*

Scientific and technological creativity is at the center of discussions about the increasingly competitive global economy (Florida, 2005; Friedman, 2005; National Academy of Sciences, 2006). Advancements in science and technology drive economic growth in many ways. For example, the creation of new fields, such as biochemistry, can in turn lead to entirely new industries, such as biotechnology (National Academy of Sciences, 2006). In fact, the American Competitiveness Initiative (ACI) reported that intellectual-property-intensive industries such as biotechnology and information technology are responsible for 40% of U.S. economic growth (ACI, 2006). Beyond its economic impact, technological innovation often improves the quality of countless areas of life, such as communication, transportation, agriculture, education, and health care.

In an effort to increase scientific creativity, national initiatives such as the ACI and the America COMPETES Act have focused on increasing both the number of students pursuing STEM (science, technology, engineering, and mathematics) degrees in the United States and the number of teachers teaching in STEM fields (National Academy of Sciences, 2006). However, broad initiatives aimed at increasing the number of individuals with STEM degrees in the job market neglect psychological attributes and other individual differences related to excellence and innovation in science and technology (Lubinski, Benbow, Webb, & Bleske-Rechek, 2006; Park, Lubinski, & Benbow, 2007). After all, only a small subset of people within a given discipline creates important scientific and technical advances. Here, we examine one important psychological attribute that underlies scientific creativity: quantitative-reasoning ability. To underscore its importance, we examine the role that individual differences in this ability play even within groups of individuals who have earned the same advanced educational degree.

Analyses of human capital and creativity typically neglect individual differences in cognitive ability among people with advanced degrees. And, indeed, most well-known measures of quantitative-reasoning ability do not have a sufficiently high ceiling for, say, individuals with doctorates in STEM fields. Our analyses required measures with enough "headroom" to capture the full ability range among highly talented individuals. The purpose of this study was to utilize such measures to ascertain the extent to which people with commensurate educational credentials differentially contribute important scientific and technical advances as a function of individual differences in ability.

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METHOD

Participants were drawn from the first three cohorts of the Study of Mathematically Precocious Youth (SMPY), a planned 50-year longitudinal study of intellectual talent (Lubinski & Benbow, 2006); only individuals whose terminal degrees could be documented were included. SMPY identified participants in these cohorts through talent searches, using students' scores on the math portion of the SAT (SAT-M) before age 13; all participants were in the top 1% of quantitative ability for their age. Cohorts 1, 2, and 3 were initially identified in 1972–1974, 1976–1978, and 1980–1983, respectively. The combined sample included 1,586 participants (1,006 men, 580 women). (For an extensive report on this 37-year longitudinal study, see Lubinski & Benbow, 2006.)

For the current study, we used Internet databases to collect data on patents and scientific publications for each participant. Publication data were collected through participants' curriculum vitae and Google Scholar (http://scholar.google.com). A participant was flagged as the author of a publication if he or she was listed as either the sole author or one in a group of authors. Publications were limited to articles in peer-reviewed journals. Because of our emphasis on STEM contributions, we did not include books, book chapters, or literary publications such as novels. Identified publications were categorized as being in STEM fields (physical sciences, engineering, mathematics, or computer science) or in the humanities (social sciences, law, education, public policy, art, history, and other humanities disciplines).

Patent data were obtained for each participant through Google Patents (http://www.google.com/patents). A participant was flagged as having secured a patent if he or she was listed as the sole inventor or as one of a group of inventors of at least one patent. We also noted whether each participant had at least one patent at a Fortune 500 company. A Fortune 500 company in this analysis was any company ranked within the top 500 on the basis of annual gross revenue as reported in *Fortune* magazine for 2007 (http://money.cnn.com/magazines/fortune/fortune500/2007/full_list/index.html). Securing a patent is a rare accomplishment (the base rate is approximately 1%; J. Huber, 1999, personal communication, October 2004), but doing so for one of the most competitive companies in the world is extraordinary and an index of extremely high quality. Such patents are products of the most highly sought intellectual capital.

First, we grouped the participants on the basis of their highest attained educational degrees (bachelor's, master's, or doctorate degrees). Then, within each degree group, we rank-ordered participants by their SAT-M scores at age 13 and placed them into quartiles. For each SAT-M quartile within each degree group, we calculated the proportion of participants with at least one patent and the proportion with at least one Fortune 500 patent. Additionally, we calculated the proportion of participants with at least one peer-reviewed publication in a STEM or humanities discipline.

Finally, to add nuance to the analysis and evaluate the significance of attending a top research university, we conducted an additional analysis focusing on STEM outcome criteria and advanced degrees. If a participant earned a master's or a doctorate degree, we noted whether the degree was earned at a top-15 university[1] or a non-top-15 university; for these two groups, we repeated the rank-ordering and quartile analysis for all STEM outcome criteria.

RESULTS

The mean age-13 SAT-M score of the sample increased across degree groups, from 547 for the bachelor's group, to 564 for the master's group, to 593 for the doctorate group. Within the entire sample, 11.4% of participants had authored at least one peer-reviewed STEM publication, 8.7% had earned at least one patent, and 3.1% had earned at least one patent at a Fortune 500 company. As the level of highest educational degree increased, the proportion of participants with these achievements increased. The percentages of participants who had written a peer-reviewed STEM publication were 2.1% for the bachelor's group, 4.2% for the master's group, and 27.9% for the doctorate group. The corresponding percentages for earning at least one patent were 4.1%, 11.0%, and 11.6%. Similarly, for Fortune 500 patents, the percentages were 2.1%, 3.2%, and 4.1%.

An initial review of these outcomes suggests that more able participants opted for more advanced degrees, and that those participants with more advanced degrees were more productive in terms of patents and publications. A more refined story emerges, however, when individual differences in cognitive abilities are taken into account within each degree category. Figure 1 illustrates that within each terminal-degree group, the likelihood of authoring a peer-reviewed STEM publication and the likelihood of earning a patent (Fortune 500 or otherwise) both increased with increasing quantitative-reasoning ability, as assessed at least 25 years earlier.

To quantify the increase in the likelihood of outcomes as a function of increasing quantitative-reasoning ability, we calculated for each criterion variable an odds ratio (OR) comparing the likelihood of the outcome in the top and bottom SAT-M quartiles (see Fig. 1). ORs greater than 1.0 indicate that the likelihood of the outcome was higher in the top quartile than in the bottom quartile. A 95% confidence interval that does not

[1]We compiled a list of top-15 STEM graduate schools based on the 2008 *U.S. News & World Report* ranking of graduate programs in biological sciences, chemistry, earth sciences, mathematics, physics, computer science, engineering, and medical research. The top 15 schools in our analysis are those schools whose programs appeared most frequently in the top 15 schools across all STEM program rankings. These schools were Stanford University, Massachusetts Institute of Technology, University of California at Berkeley, Harvard University, California Institute of Technology, University of Illinois at Urbana-Champaign, Cornell University, Princeton University, Yale University, Columbia University, University of Chicago, University of Pennsylvania, Duke University, Carnegie Mellon University, and Johns Hopkins University. We restricted our analysis to graduate degrees because only a few participants who earned undergraduate degrees at these top-15 institutions did not go on to earn a graduate degree.

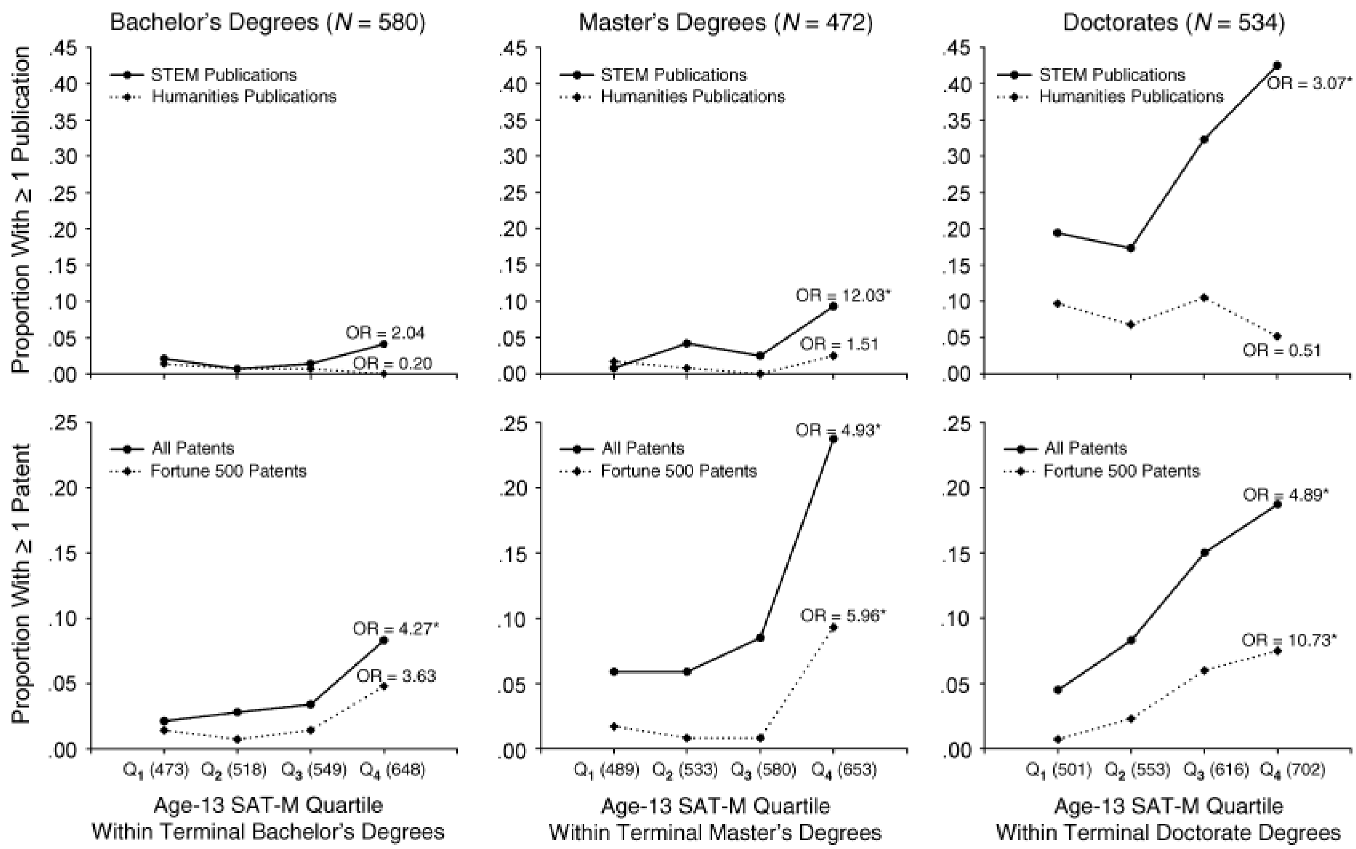

Fig. 1. **Proportions of participants with at least one peer-reviewed science, technology, engineering, or mathematics (STEM) publication and with at least one humanities publication (top row) and proportions of participants with at least one patent and with at least one Fortune 500 patent (bottom row). Participants were grouped by highest degree earned (bachelor's, master's, or doctorate). Within each degree group, participants were separated into quartiles based on math SAT scores (SAT-M) at age 13. The mean age-13 SAT-M score for each quartile is displayed in parentheses along the *x*-axis. The odds ratios (ORs) compare the likelihood of each outcome in the top and bottom SAT-M quartiles (Q_4 and Q_1, respectively). An asterisk indicates that the 95% confidence interval for the OR did not include 1.0, which means that the likelihood of the outcome was significantly greater in Q_4 than in Q_1.**

include 1.0 indicates a significant difference in likelihood between the top and bottom quartiles.

Within the bachelor's-degree group, only the OR for earning a patent (4.27) was significantly higher than 1.0. Within the master's-degree and doctorate groups, all STEM accomplishments (authoring a peer-reviewed STEM publication, earning a patent, and earning a Fortune 500 patent) had ORs significantly greater than 1 (range: 3.07–12.03). However, the OR for authoring a peer-reviewed humanities publication was not significantly different from 1 in either of these groups (master's degree: 1.51; doctorate: 0.51), which reveals the specificity of quantitative-reasoning ability for STEM areas.

Finally, what was the relationship between ability and these STEM outcomes among participants who earned their graduate degrees at top-ranked schools? As Figure 2 illustrates, among the participants who earned graduate degrees at top-15 U.S. universities, the ORs for authoring a STEM publication, earning a patent, and earning a Fortune 500 patent were all significantly higher than 1 (3.52, 5.50, and 18.68, respectively); a similar pattern was found among participants who earned graduate degrees at non-top-15 universities (ORs of 4.04, 4.86, and 5.22, respectively). Clearly, although mathematically talented students who had attended top-ranked universities were more likely to manifest impressive STEM outcomes than those who had attended lower-ranked schools, individual differences in ability mattered both significantly and substantively within both groups—particularly among students who had attended the higher-ranked schools.

DISCUSSION

Overall, these results suggest that among individuals with commensurate advanced educational degrees, individual differences in quantitative-reasoning ability predict scientific and technological innovation. In addition, our data show that measures with high ceilings are needed to uncover these individual differences and reveal their significance.

For example, among participants with doctorate degrees, the individuals in the top quartile of age-13 SAT-M scores had an average score of 702 out of a possible 800. A number of participants scored the top possible score of 800. The SAT did not measure the full scope of these participants' quantitative-reasoning

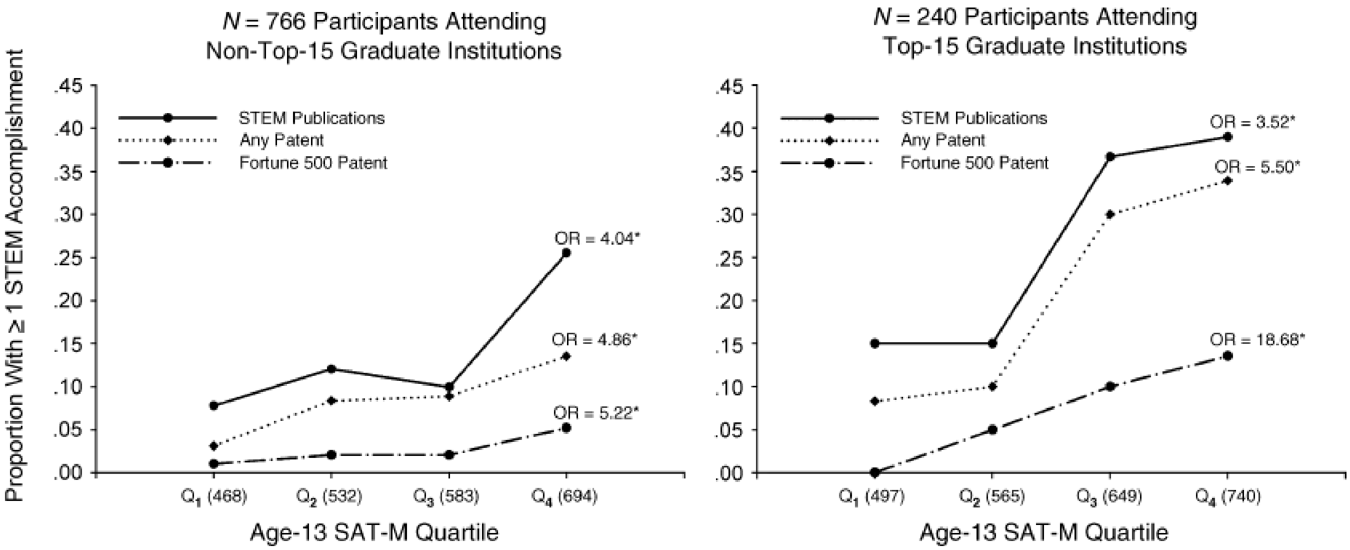

Fig. 2. The proportions of participants with a master's or doctorate degree who had at least one peer-reviewed science, technology, engineering, or mathematics (STEM) publication; at least one patent; or at least one Fortune 500 patent. Participants were grouped according to whether they earned their degree from a top-15 STEM graduate school (right panel) or a non-top-15 STEM graduate school (left panel). Within each group, participants were separated into quartiles based on math SAT scores (SAT-M) at age 13. The mean age-13 SAT-M score for each quartile is displayed in parentheses along the *x*-axis. The odds ratios (ORs) compare the likelihood of each outcome in the top and bottom SAT-M quartiles (Q_4 and Q_1, respectively). An asterisk indicates that the 95% confidence interval for the OR did not include 1.0, which means that the likelihood of the outcome was significantly greater in Q_4 than in Q_1.

ability even at age 13. Clearly, individual differences in quantitative-reasoning ability are masked when the SAT is administered to intellectually talented participants as they reach the end of high school. By high school, the majority of students of the caliber we studied are bumping up against the ceiling of the SAT-M, and this instrument is no longer capable of differentiating the exceptionally able from the able.

Our results also contradict a large body of studies reporting the lack of an empirical relationship between cognitive ability and creativity (Barron & Harrington, 1981). But these earlier investigations were compromised by design features that constrained the likelihood of uncovering the empirical relationships observed in this study. When the relationship between ability and creativity is evaluated by utilizing large sample sizes, measures with sufficiently high ceilings, criteria with high ceilings and low base rates, and a sufficient longitudinal time frame to allow expertise to develop, the importance of individual differences in ability is revealed, even among individuals with advanced degrees from top universities.

Our results also help to explain some researchers' recent suggestions that cognitive abilities are not related to future success in STEM fields (Committee on Maximizing the Potential of Women in Academic Science and Engineering, 2007; Muller et al., 2005; Vasquez & Jones, 2006). When the variability in predictors and criteria is restricted because there is not enough room at the top, the observed covariance between attributes and outcomes is severely attenuated. Psychological frameworks that attempt to model manifestations of creativity without taking these design features into account, by employing developmentally appropriate measures of cognitive functioning (Benbow & Stanley, 1996; Lubinski & Benbow, 2000, 2006), are likely to be incomplete or, more technically, underdetermined (Lubinski, 2000; Lubinski & Humphreys, 1997).[2]

Although the role that exceptional cognitive abilities play in STEM success has been downplayed in many academic circles (Committee on Maximizing the Potential of Women in Academic Science and Engineering, 2007, p. 25; Muller et al., 2005; Vasquez & Jones, 2006, p. 138), it has been embraced by leaders in industry for many years (Stross, 1996). For example, when recruiting staff for their Beijing research center, Microsoft initially identified about 2,000 Ph.D.-level students and scientists and then administered several rounds of math, IQ, and programming tests to narrow the applicant pool down to the top 150. Out of these, 20 were hired. By using cognitive-ability assessments to inform recruiting strategies for a highly educated applicant pool, Microsoft's Beijing research center has "already developed a worldwide reputation for producing cutting-edge papers for the most important scientific journals and conferences" (Friedman, 2005, p. 267).

The ACI (2006) and National Academy of Sciences (2006) reports state that innovation is required to solve the scientific

[2]Spatial ability is an important cognitive ability that could contribute to the findings reported here and add precision to forecasts based on mathematical and verbal ability. For information on how spatial ability may contribute added value to talent identification and psychological modeling of exceptional cognitive abilities and manifestations of creativity, see Humphreys, Lubinski, and Yao (1993); Gohm, Humphreys, and Yao (1998); Shea, Lubinski, and Benbow (2001); Webb, Lubinski, and Benbow (2007); and Wai, Lubinski, and Benbow (in press).

and technological problems that the world faces in the 21st century. Although increasing the number of people who attain educational degrees contributes to a more sophisticated scientific-technical workforce, relatively few individuals with such credentials contribute to important advances in STEM fields. This study reveals an important psychological attribute to take into account when attempting to identify those who do. (Of course, other psychological attributes, such as spatial ability and time devoted to the development of expertise and work, are important as well; Ceci & Williams, 2007; Lubinski & Benbow, 2000, 2006.)

We conclude that educational credentials are clearly important, as are educational opportunities at outstanding universities, but that they cannot fully substitute for ability. Our results suggest that, among other things, individual differences in cognitive ability (even when measured in early adolescence) are important to take into account when identifying and modeling exceptional scientific and technical human capital.

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