ACHIEVEMENT IN SCIENCE, TECHNOLOGY, ENGINEERING AND MATHEMATICS (STEM) AND ITS RELATIONSHIP TO STEM EDUCATIONAL DOSE: A 25-YEAR LONGITUDINAL STUDY

By

Jonathan Wai

Dissertation

Submitted to the Faculty of the

Graduate School of Vanderbilt University

in partial fulfillment of the requirements

for the degree of

DOCTOR OF PHILOSOPHY

in

Psychology

August, 2009

Nashville, Tennessee

Approved:

Professor David Lubinski

Dean Camilla P. Benbow

Professor Stephen N. Elliott

Professor James H. Steiger

Professor Andrew J. Tomarken

To my family,

Maya, Buddy, and Joybell.

And to my mother, Bessie.

ACKNOWLEDGEMENTS

I first want to thank my advisors, Dr. David Lubinski and Dr. Camilla P. Benbow for teaching me what it takes to conduct outstanding research. I am honored to be their student and I appreciate all that they have done and continue to do for me. Although I now call you David and Camilla you will always be my professors.

I also want to thank the members of my committee, Dr. James H. Steiger, Dr. Andrew J. Tomarken, and Dr. Stephen N. Elliott for teaching and supporting me since the beginning of graduate school until today. It has been my pleasure to get to know each of you and I thank you for the input you have given to make this dissertation so much better.

I want to thank my wife Maya for lovingly supporting and waiting for me to complete this dissertation and my mother Bessie for always being there since I was extremely small. Although they won't be able to read this, I also want to thank my dog Buddy for his blind devotion to me since he was a baby and my cat Joybell, who made my life a little more interesting when I took breaks. My friend Steven K. Cheng deserves great recognition for helping me format this dissertation. I would also like to thank my friends, family and lab members for all their support and encouragement. I wouldn't be here without the many people who have done little things for me along the way.

Support for this research was provided by a Research and Training Grant from the Templeton Foundation and the National Institute of Child Health and Development Grant P30 HD 15051 to the Vanderbilt Kennedy Center for Research on Human Development.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Educational Acceleration and Advanced Developmental Placement

Educational acceleration, according to one of its major proponents, Sidney Pressey, (1949, p. 2) is defined as "progress through an educational program at rates faster or ages younger than conventional." In more modern literature, which stresses for all students a matching of their rate of learning with the depth and pace of the curriculum, this might be more accurately termed "appropriate developmental placement" (Lubinski & Benbow, 2000).

With the idea of this conceptualization in mind, let us go back in time over a century to discuss the beginnings of educational acceleration. As there are literally hundreds of studies that have been conducted on the topic, it would be prohibitive to survey them all in detail. Therefore, this brief introduction will give a topographical or aerial view of findings in the area, while pointing out the landmark contributors along the way—many of whom were leading figures in the psychological sciences more generally. This review will serve as one illustration of how science cumulates by a knitting together of consistent findings from important scientific generalization.

Early History

1860's to the Early 1900's

The birth of educational acceleration as an idea likely occurred well before the 1860's, especially as the placement of students according to competence logically found its origins within the one room schoolhouse, where students of various ages were found together in relatively small numbers (Otto, 1950; Stanley & Benbow, 1982). Hence, instruction often became delivered to groups of similar competencies but not age. It was during the 1860's, however, that arguably the first formal educational accelerative program was implemented by the St. Louis school district (Witty, 1951). By 1918, Race (p. 91) had already noted that: "The idea of special classes for children with traits markedly different from the average child has been advocated by advanced thinkers in education for several years." These thinkers included Edward L. Thorndike (APA president in 1912) who noted that millions of dollars were being spent on those who were mentally challenged, whereas little was being done for those who were mentally advanced, and that the benefit to the state would primarily come from investment in the most intellectually able (Race, 1918). As Thorndike (1939, p. 593) would later write, "All competent observers of the world's work and workers will agree that a very small number of men and women of great ability and good-will account for a very large fraction of the world's progress."[1] Indeed, special courses that utilized acceleration for

[1] Thorndike's comments are mirrored by the concluding remarks from the Fund for the Advancement of Education (1957, p. 91) evaluation report, "the health and vigor of our society—and indeed even its very life—depend on making the most of all the capacities of all of our people. And it has become increasingly clear that if we are to make the most of these capacities, we must not fail to provide for the fullest possible

talented students were formed in 1920 in many cities, including Cleveland, Los Angeles, and Rochester (Witty, 1951). Early thinkers and researchers paved the way for more modern contributors, three of whom made their initial contributions in the following decade.

1920 to 1930

Any discussion of gifted children and educational acceleration would not be complete without an introduction of Leta Hollingworth (1926, 1942), who began her work with the gifted in 1916 and conducted many studies on the intellectually talented individuals she called "fortunate deviates." Hollingworth recognized and discussed with prescience many arenas in the development of intellectual talent, stating that gifted students should move through their education "at a pace that will keep them occupied" (Hollingworth, 1926, p. 273) and that they are served best when they are discovered and encouraged when very young. If this is not done for these fortunate deviates, their interests will not be engaged and their intellectual powers will not be challenged (Hollingworth, 1939, 1942).

Carl E. Seashore (1922, 1927, 1930, 1942), another president of the American Psychological Association (1911), provided leadership for establishing the *Journal of Applied Psychology* (1917) and the *Journal of Educational Psychology* (1909). Both these journals published much of the early work on gifted youth as well as on the importance of their transition from school to work. Seashore, a contemporary to

---

development of our ablest young people." Compare this to Charles Murray's contemporary argument that the gifted make up much of the cognitive elite and thus many are arguably the creators of culture (Murray, 2008). Murray (2008, p. 107) writes that the cognitive "elite are drawn overwhelmingly from among the academically gifted. We had better make sure that we do the best possible job of educating them."

Hollingworth, and an advocate for gifted students, shared a similar educational philosophy with her: "Keep each student busy at the highest level of achievement in order that [they] may be successful, happy and good" (1922, p. 644). Seashore stressed the benefits of acceleration for not only student's achievement but also their satisfaction.

A better known contemporary of Hollingworth and Seashore was, of course, Lewis M. Terman (1925, 1939, 1954), an APA president in 1923, and who initiated the legendary longitudinal study of over 1,500 gifted youth (the Genetic Studies of Genius series). Terman's study is arguably the most famous longitudinal study in all of psychology (Holahan, Sears, & Cronbach, 1995). Terman, contradicting the "early to ripen, early to rot" philosophy prevalent at the time, showed empirically that gifted children did not simply flower and wilt at an early age. Actually, they tended to be advanced in many physical, social, and emotional characteristics, disproving the commonly held belief in what he called the "doctrine of compensation" (1939, p. 67), or that certain strengths of an individual were always balanced by other weaknesses. This also supported Thorndike's (1911) observation that all good things tend to go together. Similar to statements by Hollingworth and Seashore, Terman (1954; Terman & Oden, 1947) also advocated for the use of educational acceleration to meet the needs of intellectually advanced students. He noted that there was no universal rule regarding the amount of acceleration needed for gifted students as a group, but rather that opportunities for acceleration should be tailored to the individual.

1930 to 1950

A summary report on the state of the field in 1933 (Witty & Wilkins, p. 346) concluded, "Acceleration has proved a rather effective aid in taking care of superior students." Taylor (1936) wrote in regards to the neglect of individual differences and the cheapness of public schools—specifically in their inadequacy of challenging gifted students—that "This cheapness is especially expensive for the gifted child because he gets a much smaller return on his investment of time, which is essentially his very life" (p. 11). Also during this time, Goddard (1930, 1933) strongly advocated for gifted children and the importance of letting them develop to their full capacity, stating "If democracy means equal opportunity for all, rich and poor, fortunate and unfortunate, then special classes are required; for no child has an equal opportunity in any class where he is forced to mark time because the majority are slower than he" (1933, p. 359). This demonstrates that there were many scientifically distinguished and highly visible advocates for educational acceleration during this time. It was also during this time that another two landmark figures in counseling psychology took the stage (Achter & Lubinski, 2003).

The first of these figures was E. G. Williamson (1939, 1965) who also advocated for meeting the needs of gifted children through educational acceleration, emphasizing that "genius does not always find its own way" (1939, p. 387). Williamson stressed that intellectually talented individuals ought to be appropriately identified and have their level and pattern of abilities appropriately assessed so that they might be guided to achieve satisfaction and success.

The other major figure was Sidney Pressey (1946a, 1949, 1955, 1967) who broadly published on the topic of educational acceleration in a variety of high impact outlets, heralding its benefits. His landmark publication on educational acceleration (1949) investigated its effects on large numbers of students and concluded that there were many benefits and few if any drawbacks from it. Some of his emphases were on the importance of educational acceleration for conserving time such that the prime (defined as peak biological potentiality) years can be used to contribute to one's career rather than be spent trapped in the lockstep of higher education (1946b).

As Goldberg (1958, p. 154) wrote, "From the early studies of the 1930's until the recent report by the Fund for the Advancement of Education on its Early Admissions Program (1957), acceleration has proved to be a very satisfactory method of challenging able students."

1950 to 1970

An edited volume by Paul Witty (1951) titled *The Gifted Child* synthesized much of the literature on educational acceleration and thus became a classic in the field. In an article entitled "Conserving ability in the sciences," Witty and Bloom (1955, p. 10) wrote in regards to educational acceleration that these "practices challenge the superior student and develop his ability," and that "The question is not whether provision should be made for the gifted but rather *how* it can best be offered." Nicholas Hobbs (1951, 1958), who was APA president in 1966, echoed the remarks of Williamson by saying that gifted students cannot simply find their own way and that it is important that gifted students are given educational opportunities that fit with their needs. Another important report published by Worcester (1956) summarized the conclusions of the field that educational acceleration is educationally efficacious and should be implemented by educators and practitioners. In addition, as was introduced earlier, the Fund for the Advancement of Education on its Early Admissions Program (1957) studied educational acceleration and concluded that it was a positive method of intervention for gifted students.

This leads us to another dominant figure in the psychological sciences, Leona E. Tyler (1953, 1965, 1974). She not only wrote compellingly in the area of acceleration, but was one of the most distinguished counseling psychologists of her century. (She worked on Terman's study as well). In her day, she was the author of the top textbook in counseling psychology (Tyler, 1953) as well as the major graduate text on the study of human individual differences (Tyler, 1965). Subsequent to her 1973 term as APA president, she summarized her views on educational acceleration by saying, "We must not be content with any system of universal education that provides identical treatment for all pupils. We must look for ways of diversifying education to make it fit the diverse individuals whose talents should be developed and utilized," and that "A complex society cannot regard its members as identical interchangeable parts of a social machine" (Tyler, 1974, pp. 6-7). Therefore, her views on educational acceleration are easily aligned with earlier contributors.

Important among the papers published after Pressey (1949) were not only the Fund for the Advancement of Education report (1957) and Tyler's contributions, but also a series of Bingham lectures on the development of exceptional abilities and capacities which all initially appeared in the *American Psychologist*, with the first of these lectures by Terman being published in 1954 and others following (Burt, 1957; Ghiselli, 1963;

Guilford, 1959; MacKinnon, 1962; Mackworth, 1965; Paterson, 1957; Stalnaker, 1961; Strong, 1958; Vernon, 1965; Wolfle, 1960). These lectures focused on the conservation of talent and emphasized the importance of educational placement according to intellectual readiness, and were later gathered in an edited volume by Dael Wolfle (1969) entitled *The Discovery of Talent*.

1970 to 1986

Establishing himself as a landmark figure in investigations of the importance of educational placement commensurate with educational readiness, Julian C. Stanley (1977; Keating & Stanley, 1972) initiated the Study of Mathematically Precocious Youth (SMPY) in 1971. Initially, SMPY concerned itself with developing the concept of a talent search and associated educational programs that had acceleration at their core. After their establishment, SMPY's focus shifted to conducting a longitudinal study (Benbow & Stanley, 1983). This long-term longitudinal study, now spanning 37 years, is currently being conducted by Lubinski and Benbow (2006). Gordon W. Allport, arguably the founding father of the positive psychology movement and APA President in 1939, was one of Stanley's advisors at Harvard. In 1960, Allport wrote something highly characteristic of Stanley's point of view (a view that motivated Stanley to launch SMPY):

> It is my own conviction that most of our institutions of higher learning offer intellectual fare distressingly below the digestive capacity of the gifted. I am not thinking merely of colleges that offer the frivolous course in fudge-making, but of our "best" institutions, where courses are often repetitive, routine, and devoid of challenge. Perhaps from the point of view of the average student they are adequate, but they stretch no nerve in the gifted student….Usually such a student does well, and the teacher rejoices, but in many cases the teacher should feel less joy than guilt, for he has, intentionally, beckoned the gifted student downward toward mediocrity rather than upward toward maximum self-development. (Allport, 1960, p. 68)

SMPY is now a study like Terman's (1925) but with emphasis on specific abilities and the identification of multiple cohorts over time. Stanley and his colleagues (Benbow & Lubinski, 1996, 2006; Benbow & Stanley, 1983; Fox, Brody, & Tobin, 1980; George, Cohn, & Stanley, 1979; Keating, 1976; Stanley, George, & Solano, 1977; Stanley, Keating, & Fox, 1974) demonstrated over multiple decades that using above-level ability measures (measures initially designed for older students) was an excellent way to identify the level and pattern of individual talents and, subsequently, for tailoring appropriate educational interventions to the individuality of each student (Benbow, 1991; Benbow & Stanley, 1996; Stanley, 2000). Stanley's emphasis on the importance of providing educational accelerative opportunities for those students who really want them and are ready for them is important to keep in mind. Stanley went beyond IQ or general intelligence to examine specific abilities (i.e., verbal and mathematical), which was an important advance in talent identification. Indeed Terman had missed two Nobel Laureates, William Shockley and Luis Alvarez, by utilizing only the highly verbal Stanford-Binet (Shurkin, 1992); had these two mathematically talented individuals also been given a quantitative reasoning measure they most likely would not have been missed. In the words of Lee J. Cronbach (c.f. Benbow, & Lubinski, 2006, p. 252) at Julian Stanley's 1992 festschrift, "In 100 years, when the history of gifted education is written, Lewis Terman and Julian Stanley are the two names that will be remembered."

Contemporary Findings

1986 to Present

As described above, SMPY is currently being co-directed by Lubinski and Benbow (2006) and there have been multiple empirical reports from this research team illustrating the benefits of educational acceleration or appropriate developmental placement (Benbow, Lubinski, Shea, & Eftekhari-Sanjani, 2000; Bleske-Rechek, Lubinski, & Benbow, 2004; Lubinski, Benbow, Shea, Eftekhari-Sanjani, & Halvorson, 2001; Lubinski, Webb, Morelock, & Benbow, 2001; Swiatek & Benbow, 1991a, 1991b), and the relative lack of negative effects of such educational interventions (Benbow & Lubinski, 1996; Benbow & Stanley, 1996; Lubinski & Benbow, 2006). These studies involved participants who have experienced many different components of educational acceleration and they examined educational and vocational outcomes as well as subjective feelings.

This leads us to a recent summative report, which also echoes the Bingham lectures. As there is so much evidence that is not being put to practical use on acceleration, this report is provocatively yet aptly titled, *A Nation Deceived: How Schools Hold Back America's Brightest Students* (Colangelo, Assouline, & Gross, 2004). This report was a distillation of an international summit on acceleration held at the University of Iowa, which included over two dozen distinguished scholars and educators who came to a remarkable consensus on the subject of acceleration. One would have to go back many decades to find any meeting of this scope and magnitude on acceleration. These efforts culminated in a two volume report. Volume I was more user friendly and geared towards parents, teachers, and K-12 academic administrators, whereas Volume II included articles from top researchers on acceleration and provided the scientific backing

Table 1. *Types of Educational Acceleration*

1. Early Admission to Kindergarten
2. Early Admission to First Grade
3. Grade-Skipping
4. Continuous Progress
5. Self-Paced Instruction
6. Subject-Matter Acceleration/Partial Acceleration
7. Combined Classes
8. Curriculum Compacting
9. Telescoping Curriculum
10. Mentoring
11. Extracurricular Programs
12. Correspondence Courses
13. Early Graduation
14. Concurrent/Dual Enrollment
15. Advanced Placement
16. Credit by Examination
17. Acceleration in College
18. Early Entrance into Middle School, High School, or College

for the distillation of recommended best practices found in Volume I. The authors argue that despite the research evidence that has accumulated over many decades, “America’s schools routinely avoid academic acceleration, the easiest and most effective way to help highly capable students” (p. 53, v. 1). Ways to solve this implementation problem were offered.

Professional educators in gifted education currently recommend that acceleration and enrichment should be combined for the greatest impact (National Mathematics Advisory Panel, 2008; Rodgers, 2007). Most recently, the National Mathematics Advisory Panel (2008) included in their report a chapter on the gifted and acceleration and concluded that mathematically gifted students who are motivated should be allowed to be accelerated.

Now that the history of educational acceleration in general has been reviewed, let us consider the different kinds of acceleration that are currently available to students. What are these methods of academic acceleration that America's schools too often avoid or fail to completely implement?

Types of Educational Acceleration

In the early 1920's when the first major studies of acceleration were being conducted, there were relatively few kinds of acceleration options available to students. Over time, however, many different forms of educational acceleration have become available. In order to present a broad picture of what is currently accessible to students, Table 1 includes a representative sample of 18 different types of educational acceleration (for a detailed explanation of each of these kinds of acceleration, see Southern & Jones, 2004, p. 6). There are multiple components of educational acceleration currently available to students. Researchers who are studying the efficacies of such components usually are prohibited on practical grounds from allowing one student (or a group of students) to accelerate while simultaneously denying that opportunity to another if both students (or both groups of students) are ready and eager to accelerate. This is because they cannot control access to the intervention. If shut out of one program, a student can attempt to access another. This means randomized control trials (RCTs) are not feasible.

Research on Educational Acceleration is Quasi-Experimental

In the field of education, whether a student accelerates or not is, and should be, a personal decision. Like playing a musical instrument, participating in a play, or trying out for a sport, students cannot be randomly assigned because they must choose, and treatment is difficult to withhold as parents can "shop around." Studies on educational acceleration, therefore, must be quasi-experimental (Campbell & Stanley, 1963; Cook & Campbell, 1979; Shadish, Cook, & Campbell, 2002). Nevertheless, such studies provide a valuable contribution by studying those who have taken advantage of those opportunities, characterizing their psychological attributes, and tracking their educational and career outcomes. Studies in the past have examined a wide array of educational options, including advanced subject matter placement, special classes, and taking college courses in high school (Benbow & Stanley, 1996; Colangelo et al. 2004; Heller, Mönks, Sternberg, & Subotnik, 2000; Kulik & Kulik, 1984). In addition to this, many studies have compared those participants receiving one component of educational opportunity to those participants who did not receive that component, for example comparing participants who had a college course when in high school to those who did not (Brody, Assouline, & Stanley, 1990; Colangelo et al., 2004). The individual studies are too numerous to review individually here. However, a major meta-analysis by Kulik and Kulik (1984) examining 26 studies concluded that accelerative components (examined individually) generally have a large effect. Kulik & Kulik (1984) did not, however, examine adult achievements, which is something this dissertation does examine. These findings, when combined with the most recent findings in *A Nation Deceived* (2004) and the report of the National Mathematics Advisory Panel (2008) present a powerful case for the positive impact of accelerative components on student learning, and represent the general consensus or state of the field.

Current Research Questions

This dissertation is different in two fundamental ways from previous research. First, this study aims to provide a unique contribution by conceptualizing and quantifying educational experiences as a "dose concept." Instead of examining each component in isolation, I will examine components in combination, specifically looking at the "dose" of educational components that an individual participates in.

Another way this study will break new ground is that it will evaluate not only educational attainment (e.g., earning a PhD) but also subsequent creative accomplishments (e.g., publishing a refereed article, inventing a patent, or earning tenure) as well as occupational attainments. Because we already know the educational efficacy of acceleration on educational outcomes for intellectually talented students (Colangelo et al., 2004; Colangelo & Davis, 1997, 2003), I will attempt to assess how differential doses of educational opportunities beyond the norm relate to creative outcomes and occupational attainment over 25 years later.

I want to note here that my conceptualization of educational dose encompasses more than acceleration, as there are components to dose that go beyond "progress through an educational program at rates faster or ages younger than conventional" (Pressey, 1949, p. 2). For example, educational interventions such as participating in a math or science competition are not formally defined as acceleration even though advanced content is typically accessed, whereas taking a college course while still in high school is formally defined as acceleration. See Figure 1 for examples as well as Table 2 for a description of the terms included in Figure 1.

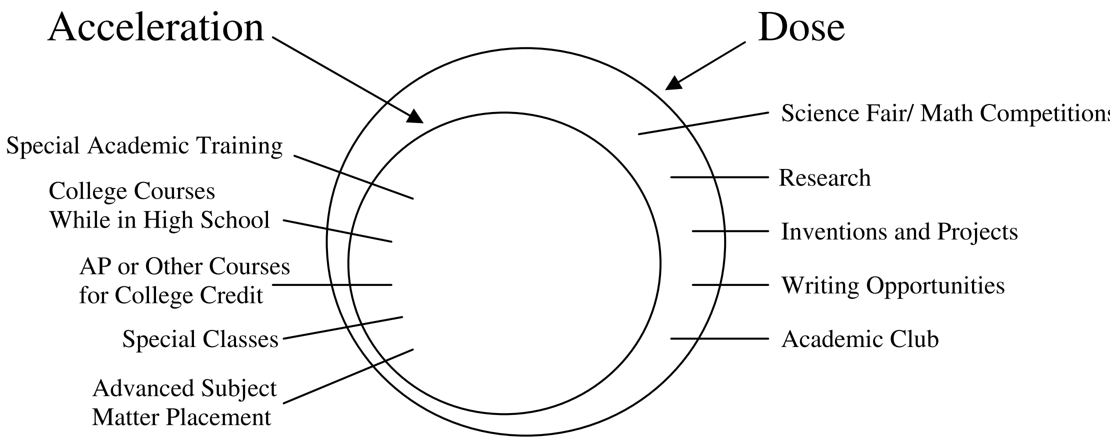


Figure 1. Illustration of How Educational Dose
Encompasses Acceleration

Table 2. Description of Educational Dose Components Found in Figure 1

Special Academic Training	Having learned a subject outside of the regular curriculum or having any special training from parents, relatives or other adults, schools, or others.
College Courses While in High School	Having taken a college course while still in high school.
AP or Other Courses for College Credit	Having taken an AP or College Board Achievement Test for college credit.
Science Fair/Math Competitions	Having participated in a science fair or math competition.
Special Classes	Having taken a special class.
Research	Having conducted research.
Inventions and Projects	Having an invention or a special project.
Advanced Subject Matter Placement	Having taken advanced subject matter placement.
Writing Opportunities	Having edited a paper or publication, written a published magazine article, presented a paper or participated in a colloquium, written a published scientific article or book chapter, written a published news article, or having a publication in preparation.
Academic Club	Having participated in an academic club.

With this introduction, let us now turn to the first new area of investigation, and the concept of educational dose.

The Concept of Educational Dose

In the field of medicine, the concept of regulating dose according to individual differences is routine. Many medications are prescribed according to *physical* individual differences parameters such as age, weight, sex, and other aspects of human individuality. However, what about for the field of education? What is the most appropriate educationally effective supplement for exceptionally talented students who want and need challenges beyond the typical school options, and how should these opportunities be tailored to suit the nuances of their *psychological* individuality? How much of an intervention (or educational dose) is necessary to achieve positive long term outcomes? This information is important for educational programming and counseling of intellectually talented students. We already know that some critical dimensions of individual differences (Lubinski, 2000) can serve as guideposts (Lubinski & Benbow, 2000): level of general ability, level and pattern of specific abilities, interests, personality, and conative factors indicative of individual differences in style or tempo (Achter & Lubinski, 2003; Lubinski & Benbow, 2000, 2006). Other determinants are also important.

Educators, for example, should provide curricular flexibility (Benbow & Stanley, 1996; Stanley, 2000), allowing each student to choose from the buffet those educational opportunities most suited to their taste. Then each talented person can best satisfy their unique configuration of needs. After all, there are many different forms of advanced educational opportunities (see Tables 1 and 2) including special academic training, special classes, advanced subject matter placement, AP or other courses for college credit, and college courses while in high school (see specifically Table 2 for technical clarification of the aforementioned terms). If a student is advanced in subject matter, takes special classes, and takes AP courses, they may not have to take a college course in high school to have their educational needs met. Or perhaps a challenging summer program is sufficient to keep talented students motivated and may even give them an intellectual and/or motivational boost. I hypothesize that those with a higher dose of educational opportunities beyond the norm will have higher achievements in comparison to those with a relatively lower dose of educational opportunities regardless of how the dose is configured. For example, what matters most when you diet or exercise is not that you must eat one particular type of food (e.g., celery, weight loss shakes, or nutritional bars) or exercise in a particular way (e.g., cycling, running, rowing, or weight lifting) but that you have a good mix of healthy foods and healthy opportunities to get into shape, respectively. No one thing is required. Multiple components are, in essence, functionally interchangeable. And just as powerful constructs are carried through multiple measures, powerful educational interventions are also carried through multiple opportunities. By drawing on the examples of diet and exercise, the concept of developmentally appropriate educational dose with a focus on functionally equivalent opportunities would appear to be an important concept.

Hereafter, the concept of educational dose will be defined as the number of challenging pre-college educational opportunities beyond what is required. This investigation focuses on pre-college educational opportunities because, in the college setting, placement according to competence is already commonly practiced. For example, if a student wishes to take more classes in college to graduate in three years instead of the standard four, what matters is whether the student has the prerequisites to do so, not limitations from administrators, since taking a heavy load (and being responsible for the consequences) is up to the student for the most part. An example at the college level would be what Yale University calls “Acceleration Credit,” which includes the granting to educationally advanced students credit for their work in Advanced Placement (AP), International Baccalaureate (IB) courses or A-level examinations. Beyond this, current examples in the graduate setting are joint BA/MA degrees and the newly offered 2-year law degree for motivated students with exceptional ability at Northwestern University. As the Northwestern Law School Dean, Van Zandt, discussed recently in the *Chronicle of Higher Education* (Mangan, June 20, 2008), “There’s a strong sense in legal academics that the third year is not well used.”

Although it can be argued that educational dose in general is likely important for multiple educational and vocational outcomes, the focus of my dissertation is on Science, Technology, Engineering, and Mathematics (STEM) criteria. This is because there is a contemporary emphasis on STEM. Therefore, it is logical to focus on STEM educational dose (see Figure 2 for further explanation as well as the next section). As for outcomes, there are multiple waysto achieve in STEM, but I am restricting my focus to the following criteria: earning a STEM PhD, STEM publications, STEM tenure, STEM patents, and entering STEM occupations.

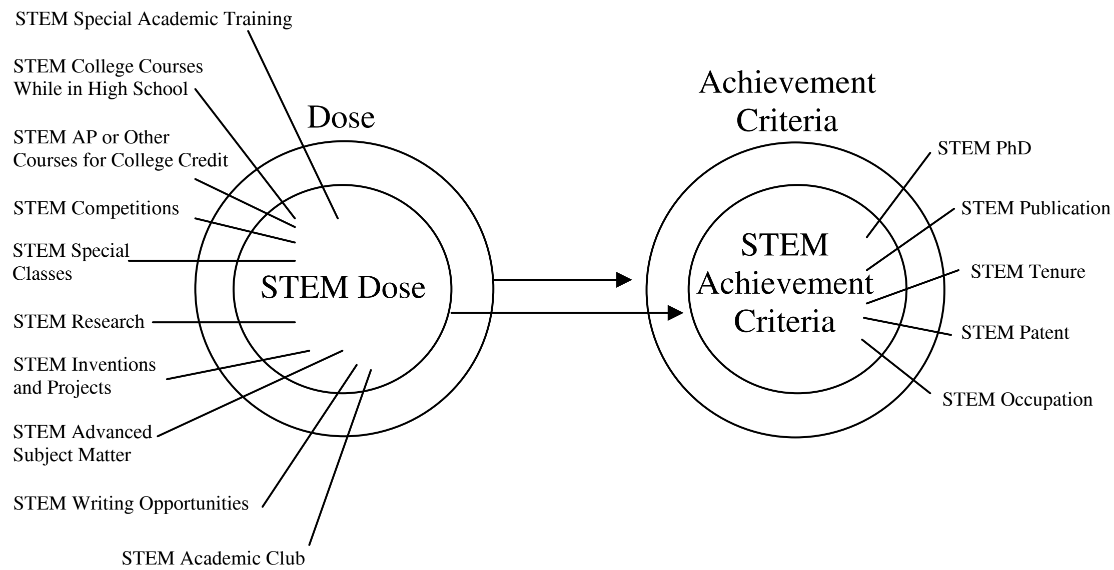


Figure 2. Illustration of the Relationship between STEM Educational Dose and STEM Outcomes

One focus is on creativity, since each of these criteria (but in particular, STEM patents, STEM publications and STEM tenure) can be considered to involve innovations in various degrees. Just as there are many ways to build an impressive academic curriculum vitae, there are many ways to manifest achievement in STEM. There is not just one path that must be followed. So a mix of criteria is preferred (Austin & Villanova, 1992). I will discuss STEM educational dose in more detail in the next section.

STEM Educational Dose

The Pool of STEM Innovators

Scientific journals and the popular press have discussed at length the importance of sustaining and extending the pool of STEM professionals (Advancing Research in Science and Engineering, 2008; American Competitiveness Initiative, 2006; Asia

Society, 2006; Holden, 2008; National Academy of Sciences, 2005; National Mathematics Advisory Panel, 2008), as well as identifying the next generation of STEM leaders and innovators (Friedman, 2005). However, it is important to distinguish between increasing scientific literacy in the general population and identifying, educating, and encouraging STEM leaders. This distinction is not only relevant for each student's optimal development, but it also has broader social implications. For example, the National Academy of Sciences has published *Rising Above the Gathering Storm* (2005), the United States has recently initiated an *American Competitiveness Initiative* (2006), and the American Academy of Arts and Sciences just published a report on *Advancing Research in Science and Engineering* (2008). One aspect that has not been stressed by these reports is the special importance of tailoring educational experiences to the unique needs of intellectually talented youth with potential to become the STEM innovators of tomorrow. Much of the writing on this topic does not take into account individual differences in learning rates. This dissertation highlights the importance of combining exceptional ability with high doses of educational opportunities in STEM. And that collectively, when the two are combined the likelihood of subsequent STEM innovation is markedly enhanced.

Educational Dose Restricted to STEM

Due to the national (and international) attention given to the importance of identifying and nurturing STEM talent, there is a need to assess the impact of STEM educational dose on STEM achievement. I will thus attempt to quantify the concept of pre-college STEM educational dose. Although it would make sense for those who had higher educational doses in general to achieve more in general (e.g., in either the humanities or STEM fields), the focus of my dissertation is on STEM achievements as related to STEM educational experiences, and specifically the dose of those experiences. Hereafter, the concept of STEM educational dose will therefore be defined as the number of challenging pre-college STEM educational opportunities beyond what is required.

Definition of a Talent Search

Academic talent searches are conducted every year across the United States. Typically the Scholastic Assessment Test (SAT), specifically the math (SAT-M) and verbal (SAT-V) sections, which are designed for college going high school seniors (at about age 17), are given to participants before the age of 13. This is considered out of range testing and the idea is that students who are scoring at the very top of their within grade standardized tests will have the opportunity to be measured accurately with a psychometric tool that has enough "ceiling" to adequately capture the scope of their intellectual capacity.

Definition of a Study of Mathematically Precocious Youth (SMPY) Talent Search Cohort

The data for my dissertation comes from SMPY, which, as mentioned before, is planned longitudinal study including multiple cohorts of intellectually talented participants. These cohorts were identified at different times and therefore they are named differently. Further detail about the cohorts of participants included in this study can be found in the next section.

Components of STEM Educational Dose

Table 1 includes many of the general types of advanced educational opportunities available to students. However, since the focus will be on STEM educational experiences, it makes sense to include examples of the types of STEM educational opportunities that were investigated. Tables 3, 4 and 5 introduce the components of STEM educational dose. Over time more opportunities have become available to students, thus, within Table 4, the number of different STEM accelerative components that were available for students in each talent search cohort increases over successive years. Table 3 includes the STEM dose level; Table 4 shows the STEM dose type and whether each type was available to a particular cohort; and Table 5 includes the technical clarification of each of the STEM dose components. The components of dose were determined by examining the initial surveys as well as the follow up surveys for each of the cohorts and finding all the possible components that could be isolated as STEM specific. Anything that was not clearly STEM specific was not included as part of the components of dose, so this determination of the components was done with excellent reliability.

Table 3. STEM Educational Dose Level of 1972-74 Talent Search (SAT-M ≥ 500), 1976-78 Talent Search (SAT-M ≥ 500), and 1980-83 Talent Search (SAT-M ≥ 700) participants with before age 13 SAT-M data and 20-year follow-up data.

STEM Dose Level or Amount	1972-74 Talent Search (Cohort 1)	1976-78 Talent Search (Cohort 2)	1980-83 Talent Search (Cohort 3)
0	130	47	0
1	305	54	12
2	223	95	19
3	97	103	32
4	21	93	19
5	0	57	33
6	0	14	46
7	0	4	39
8	0	0	18
9	0	0	3
10	0	0	3

Table 4. STEM Dose Components Available by Cohort

	STEM Dose Components		
	1972-74 Talent Search (Cohort 1)	1976-78 Talent Search (Cohort 2)	1980-83 Talent Search (Cohort 3)
Special Academic Training	Yes	Yes	Yes
College Courses While in High School	Yes	Yes	Yes
AP or Other Courses for College Credit	Yes	Yes	Yes
Science Fair/Math Competitions	Yes	Yes	Yes
Special Classes		Yes	Yes
Research		Yes	Yes
Inventions and Projects		Yes	Yes
Advanced Subject Matter Placement			Yes
Writing Opportunities			Yes
Academic Club			Yes

Table 5. Technical Clarification of Each of the STEM Dose Components

Special Academic Training	Having learned a STEM subject outside of the regular curriculum or having any special STEM training from parents, relatives or other adults, schools, or others.
College Courses While in High School	Having taken a college course in STEM while still in high school.
AP or Other Courses for College Credit	Having taken an AP or College Board Achievement Test for college credit in STEM.
Science Fair/Math Competitions	Having participated in a STEM competition.
Special Classes	Having taken a special class in a STEM area.
Research	Having conducted research in STEM.
Inventions and Projects	Having an invention or a special project in STEM.
Advanced Subject Matter Placement	Having taken advanced subject matter placement in STEM.
Writing Opportunities	Having edited a paper or publication, written a published magazine article, presented a paper or participated in a colloquium, written a published scientific article or book chapter, written a published news article, or having a publication in preparation in STEM.
Academic Club	Having participated in an academic club in STEM.
Special Academic Training	Having learned a STEM subject outside of the regular curriculum or having any special STEM training from parents, relatives or other adults, schools, or others.

CHAPTER II

STUDY 1: THE RELATIONSHIP BETWEEN STEM EDUCATIONAL DOSE AND STEM OUTCOMES

Methods

Participants for Study 1

For Study 1, participants were taken from the first three of SMPY's (Lubinski & Benbow, 2006) talent search cohorts (i.e., the 1972-1974, 1976-1978, and 1980-1983 talent searches). Three groups were formed. The first two groups were the 1972-1974 (Cohort 1; Group 1) and 1976-1978 (Cohort 2; Group 2) talent search participants who scored SAT-M $\geq$ 500 by age 13 (those in the top 1 in 200 in quantitative reasoning ability) and who also had 20-year follow up data. Group 3included the 1980-1983 (Cohort 3) talent search participants who scored SAT-M $\geq$ 700 by age 13 (those in the top 1 in 10,000 in quantitative reasoning ability) who also had 20-year follow-up data. Participants in this cohort were initially identified based on either SAT-M $\geq$ 700 or SAT-V$\geq$ 630; therefore, because the focus here is on STEM, my analyses were restricted to the $\geq$700 SAT-M grouping. The average age 13 SAT-M score for Cohort 1 is 568 (with participants selected with SAT-M $\geq$ 500), for Cohort 2 it is 571 (SAT-M $\geq$ 500), and for Cohort 3 it is 729 (SAT-M $\geq$ 700).

The reason for focusing on SAT-M scores is because those with strengths in mathematical ability have the greatest promise for STEM achievements (Park et al. 2007, 2008). The SAT-M is ideal for identifying STEM talent because of the abstract and novel nature of the questions for 13 year olds (Benbow, 1988). The reason for focusing on those with SAT-M scores ≥ 500 for Cohorts 1 and 2 is because this is the cut score typically used for entrance into summer residential programs for STEM opportunities. Students scoring at this level can assimilate a full high school course in math or science (e.g., chemistry) in three weeks time if given the opportunity. Students scoring SAT-M ≥ 700, on average, can assimilate twice as much course material. The sample sizes, by sex, for each talent search cohort based on the aforementioned criteria were as follows: 1972-1974 talent search (M = 518, F = 258); 1976-1978 talent search (M = 341, F = 126); and 1980-1983 talent search (M = 203, F = 21).

Predictor for Study 1

STEM Educational Dose

For Study 1, STEM educational dose is the focal predictor. An individual does not have to take a STEM AP course, have special STEM training, or have taken a STEM college course in high school to have their educational needs met. Rather, what matters are the individual's STEM educational opportunities or dose level. Thus, within each cohort, STEM educational experiences beyond the typical fare were weighted equally (each given a weight of 1) and within each talent search cohort the frequency of different STEM educational experiences were summed to index the dose level. As a clarifying example, a STEM dose of 3 could equal AP or other exams for college credit + special academic training + college courses in high school or 3 could equal research + special classes + academic competition. Participants in the 1972-74 talent search had the fewest opportunities, and participants in the 1980-83 talent search have had the most (see Table 4). Thus, the opportunity for educational experiences beyond the norm has changed over time, with more recently identified cohorts having more opportunities available. In accordance with this, the median dose response for each of the talent search cohorts is different, increasing over time, but also as a function of ability level. For example, in the 1972-1974 talent search (Cohort 1) the STEM median educational dose is 1, in the 1976-1978 talent search (Cohort 2) the median is 3, and in the 1980-1983 talent search (Cohort 3) the median is 5, respectively (see Table 3).

SAT-Mathematics

The mathematics subtest of the Scholastic Assessment Test (SAT-M) was administered to talent search participants in each cohort at time of initial testing to select participants. SAT-M scores also were used to assess ability differences among dose levels within each cohort when evaluating the potential impact of dose on the outcomes under analysis.

Criteria for Study 1

Description of Criterion Variables

The attainment of STEM PhDs, STEM publications, STEM tenure, patents, and STEM occupations are the criteria under investigation. At approximately age 33, participants from each of the talent search cohorts were surveyed through either the internet, mail, or by phone (Benbow et al., 2000; Lubinski et al., 2006). The follow up dates for this data collection were from 1992-94 for the 1972-74 talent search (Cohort 1), from 1996-99 for the 1976-78 talent search (Cohort 2), and from 2003-04 for the 1980-83 talent search (Cohort 3). Whether an individual had earned a STEM PhD was determined through the age-33 follow up surveys and augmented by an internet search. Some participants who did not report that they had earned a STEM PhD or who did not respond to the age-33 survey did report that they had earned a STEM PhD on their websites. For those participants who had attained a position in the professoriate or who had earned a doctorate by the time of the age 33 follow-up, their tenure standing was determined through their academic websites. To ensure that the participant found on an academic website was indeed the correct person, additional information was used (e.g., college attended or major in college) for verification. To update participants' achievement data, Google patents was used to determine whether they had secured a patent (www.google.com/patents). Google scholar (www.google.com/scholar) was used to determine whether a participant had secured a peer reviewed publication, with the program Publish or Perish—which utilizes Google scholar—as the primary tool used (www.harzing.com/pop.htm). Occupational data was obtained utilizing the age 33 follow-up surveys. For all three cohorts, these follow up data were collected at least a quarter of a century after the participant's initial identification with the exception of occupational data which were collected 20 years after initial identification.

Analyses

First, for each cohort separately, I established high and low STEM dose groups using a median split for analytic purposes. Oftentimes, a median split can be used to determine whether a variable is unimportant, so here I am using a median split to see if we have a phenomenon. The median itself was included in either the high or low dose group to achieve as close to a 50/50 split as possible. By examining the STEM dose frequencies by cohort in Table 3, it can be seen that this strategy resulted in the median being included in the low dose group for Cohorts 1 (N's: low = 435, high = 341) and 3 (N's low = 115, high = 109), and the median being included in the high dose group for Cohort 2 (N's: low = 196, high = 271). Following this classification, for each cohort, I plotted the high dose versus the low dose groups on all criteria: STEM PhDs, STEM publications, STEM tenure, patents, and STEM occupations. I hypothesized that for each cohort, the high dose group would have a higher proportion securing each outcome than the low dose group. Following this, a more nuanced examination of these data was executed that takes ability into account in the following way.

For each cohort, I plotted for the low and high dose groups their age 13 SAT-M means on the x-axis, and the proportion earning a particular STEM outcome on the y-axis. I hypothesized that within each cohort the SAT-M differences between the high and low dose group would be rather small and statistically and substantively insignificant, whereas the difference between the proportions of participants achieving a particular outcome in the high versus the low dose group would be rather large and statistically and substantively significant.

To test whether there is a significant difference between the average age 13 SAT-M scores for the high and low dose groups, I used independent sample t-tests. To determine whether the difference between the proportions earning a particular STEM outcome are large and statistically significant, a more involved analysis was required.

For this analysis, I used confidence intervals around the difference between (high versus low) proportions as well as confidence intervals around the ratios of proportions or relative risk.

Confidence Intervals around the Differences between Proportions

The formula I used for the 95% confidence interval around the differences between proportions is the following, where p_1 and p_2 stand for the two different proportions for each outcome variable with p_1 being the proportion of the high dose group (Agresti, 2002, 2007):

$$p_1 - p_2 \pm 1.96\sqrt{\frac{p_1(1-p_1)}{n_1} + \frac{p_2(1-p_2)}{n_2}}\ . \qquad (1)$$

For each of the statistical analyses I expected that the 95% confidence intervals would not include zero showing that the differences between proportions earning STEM outcomes in the high and low STEM dose groups was statistically significant.

Confidence Intervals around the Ratios of Proportions

In addition, for a final analysis, confidence intervals around the ratio of proportions or relative risk (RR) were utilized. Confidence intervals around the relative risk $\left(\frac{p_1}{p_2}\right)$ allow a probability statement in comparing the likelihood of being in the high STEM dose group versus the low STEM dose group on the attainment of a particular outcome (such as a STEM PhD). I anticipated that those in the high STEM dose group relative to those in the low STEM dose group would have a higher likelihood of earning

STEM outcomes, and confidence intervals around the RR allowed me to ascertain the degree to which this difference is statistically significant.

$$\ln\left(\frac{p_1}{p_2}\right) \pm 1.96\sqrt{\frac{1-p_1}{n_1 p_1}+\frac{1-p_2}{n_2 p_2}} \qquad (2)$$

The above formula (Agresti, 2002, 2007) is used because the distribution of RR was skewed as RR ranges from 0 to possibly infinity and ln (RR) was approximately normally distributed and this permitted the construction of a confidence interval which was symmetric around ln (RR). 95% confidence limits for RR are obtained by exponentiating the upper and lower bounds for ln (RR) obtained from Equation 2, specifically:

Upper limit RR = $e^{\text{upper limit ln (RR)}}$ (3)

Lower limit RR = $e^{\text{lower limit ln (RR)}}$ (4)

I anticipated that for each of the comparisons (between the high STEM dose and low STEM dose groups), the confidence intervals around the relative risk would not include 1.0, leading to a conclusion that there was a statistically significant difference between the high STEM dose and low STEM dose groups on the earning of STEM outcomes.

Replications

Built into Study 1 is a series of replications over all three cohorts. The overall aim of Study 1 was to demonstrate a similar pattern (Lykken, 1968; Meehl, 1978; Steen, 1988) across multiple STEM achievement outcomes. This was revealed by consistently more attainment in STEM, or a greater likelihood of STEM achievement, as a function of STEM educational dose (i.e., high versus low dose), across all three cohorts.

The implications of Study 1, if positive results were obtained, would be that the level of STEM educational dose (high versus low) is positively related to STEM outcome criteria (with SAT-M taken into account) and that the educational dose for these intellectually talented youths is likely to be educationally efficacious for these achievements (as practice is in athletics, music, and other talent development domains).

Results

Figures 3, 4, 5, 6, and 7 include the data within each cohort examining the relationship between a high or low STEM dose and the proportions earning a particular STEM outcome. In each of the graphs, circles indicate Cohort 1, triangles Cohort 2, and squares Cohort 3. The low dose group is indicated by an open or unfilled shape and the high dose group is indicated by a filled shape. So, for example, an open circle would indicate the low dose group for Cohort 1, whereas the filled square would indicate the high dose group for Cohort 3. SAT-M scores before age 13 are plotted on the x-axis for the low and high dose groups and the proportion of each group earning a particular STEM outcome is plotted on the y-axis.

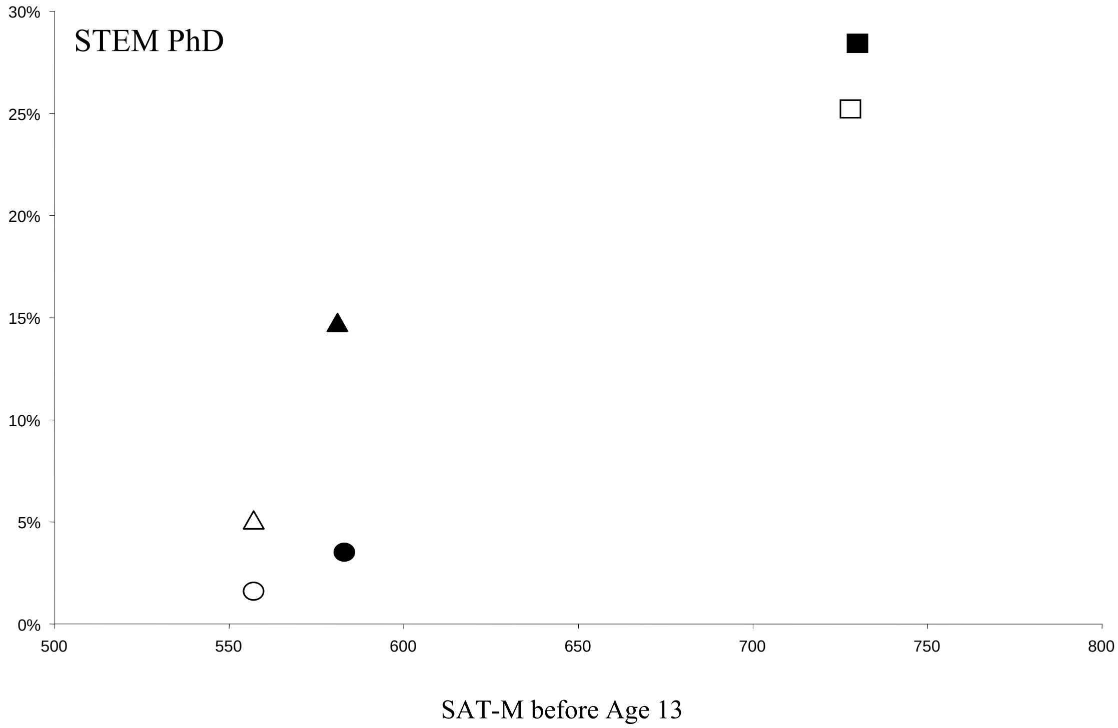


Figure 3. Proportions of participants earning a STEM PhD
by cohort, dose level, and ability level

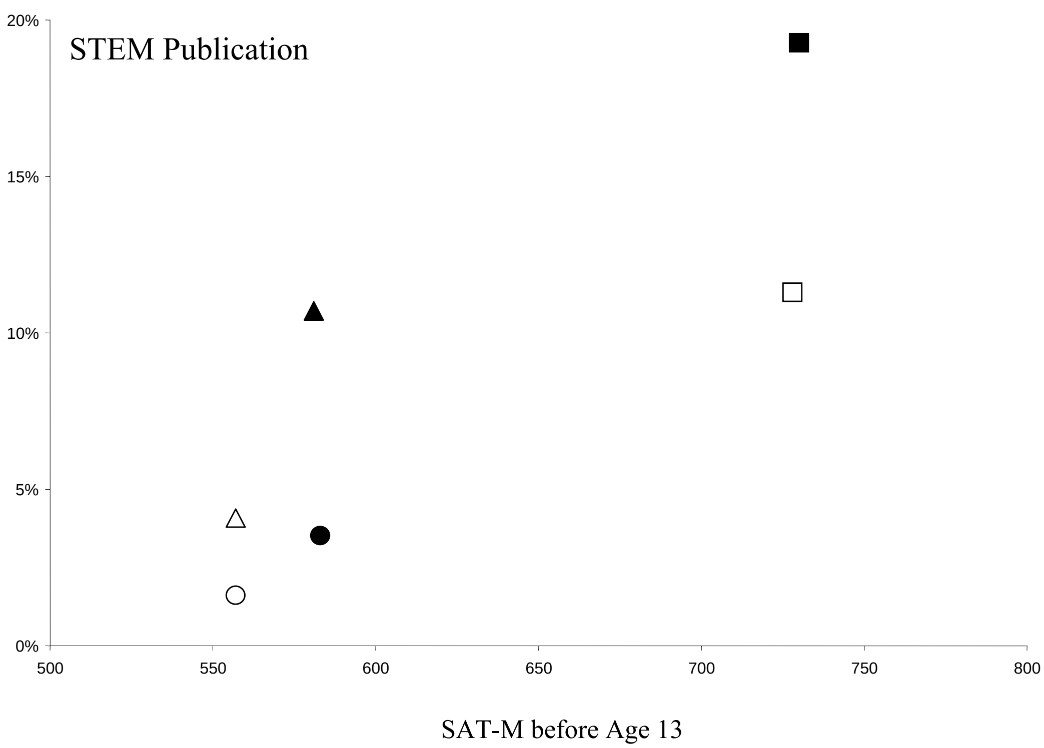


Figure 4. Proportions of participants earning a STEM publication
by cohort, dose level, and ability level

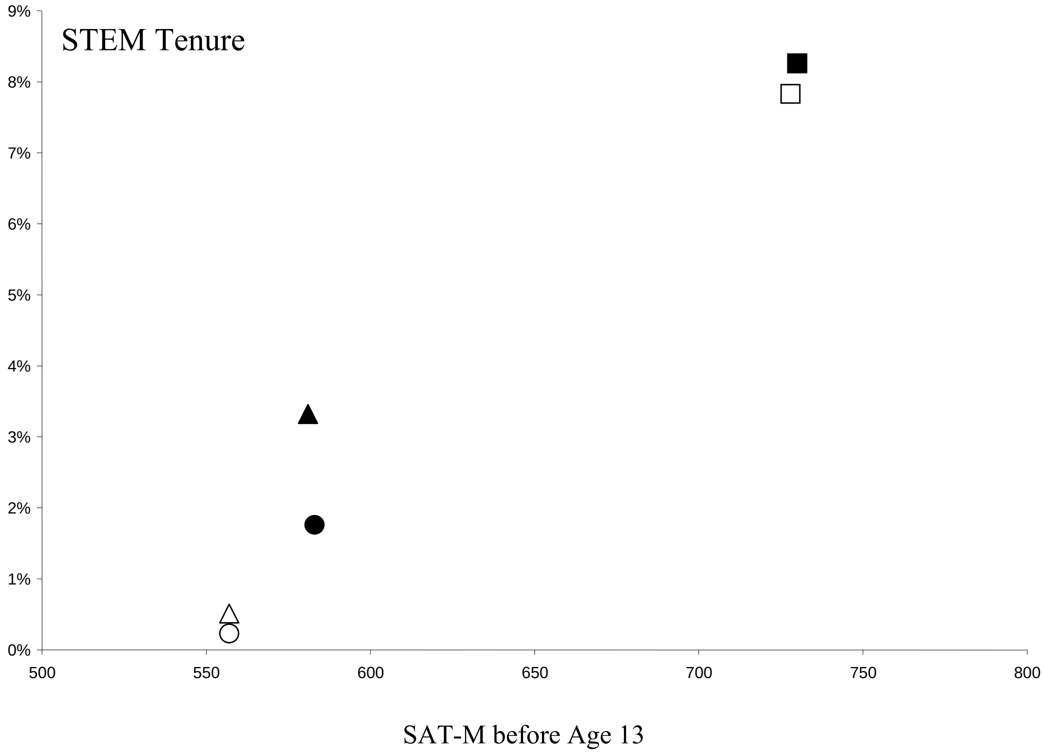


Figure 5. Proportion of participants earning STEM tenure
by cohort, dose level, and ability level

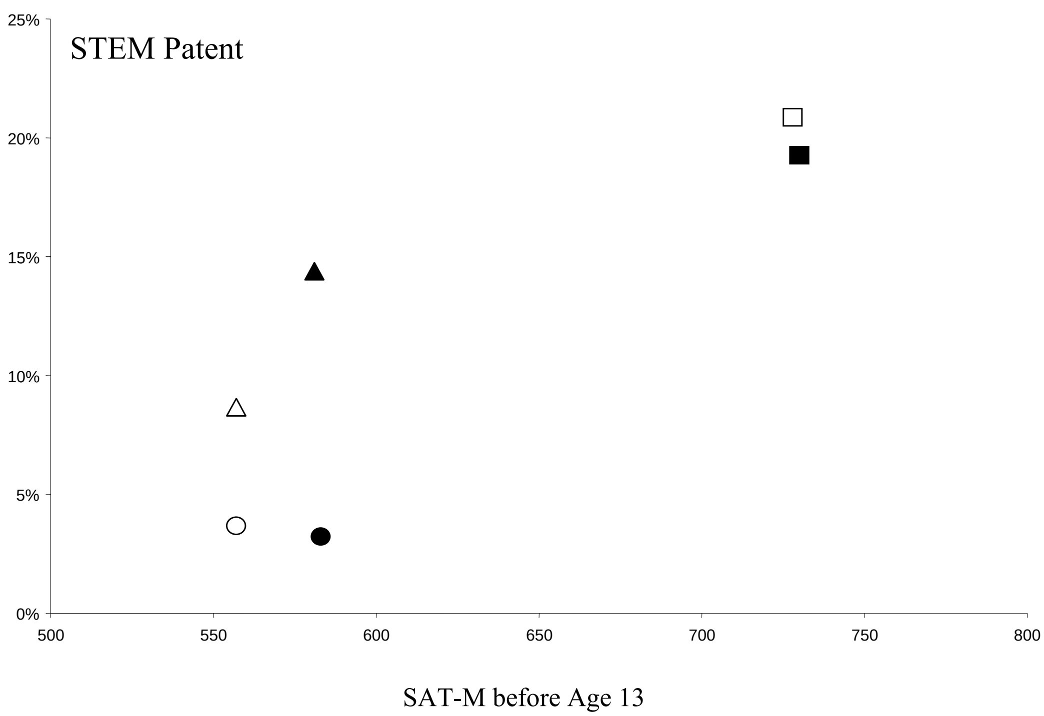


Figure 6. Proportion of participants earning a STEM patent
by cohort, dose level, and ability level

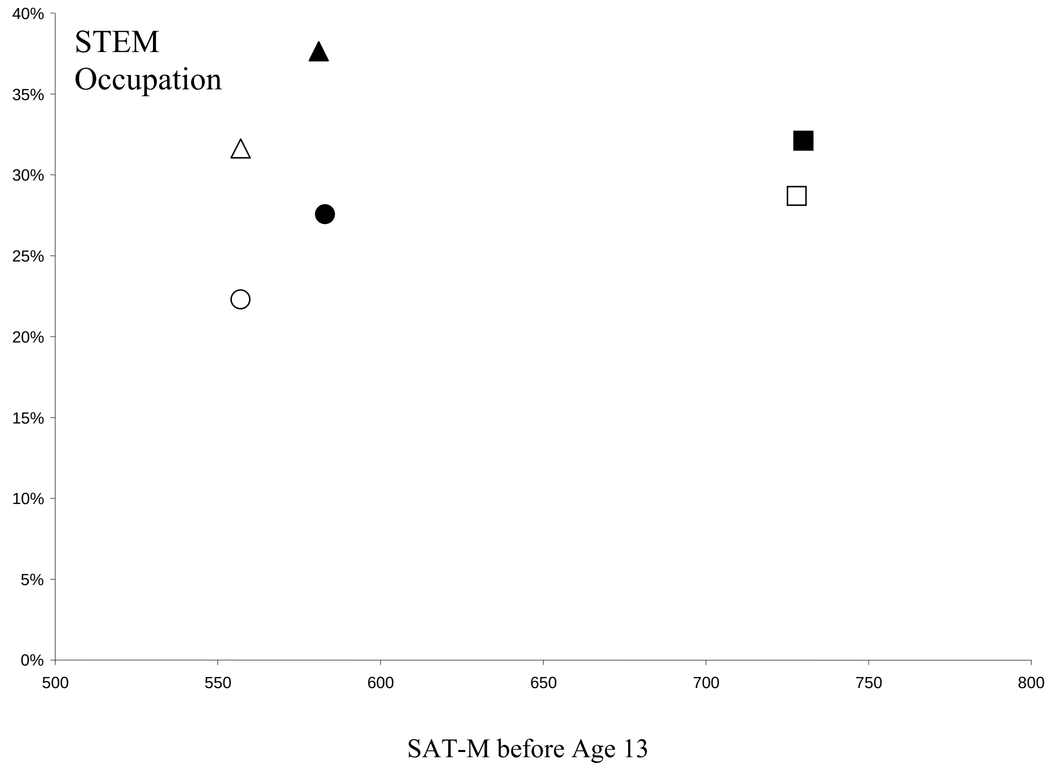


Figure 7. Proportion of participants earning a STEM occupation by cohort, dose level, and ability level

SAT-M Differences

First, it is important to note that the SAT-M differences between the high and low STEM dose groups within each cohort were relatively small. The SAT-M averages for each of the groups were as follows: Cohort 1 (Low = 557, High = 583, Difference = 26 points); Cohort 2 (L = 557, H = 581, D = 24 points); Cohort 3 (L = 728, H = 730, D = 2 points). Independent sample t-tests were conducted to determine whether these differences were significant. For Cohorts 1 and 2, these differences were significant (Cohort 1: $t = 6.585$, $p < .001$; Cohort 2: $t = 4.836$, $p < .001$). However, for Cohort 3 the difference was not ($t = 0.425$, $p = .671$). Although the SAT-M mean differences between the high and low dose groups for Cohorts 1 and 2 were statistically significant, it is important to keep in mind that these differences may not mean that much substantively. For example, within the top 1% of math ability, when comparing the top quartile to the bottom quartile on STEM outcomes in an earlier study (e.g., STEM PhDs, patents, tenure) the SAT-M difference was approximately 170 points and this difference was associated with a doubling of the relative risk of achieving such outcomes (Wai, Lubinski, & Benbow, 2005). Therefore, 26 and 24 point differences likely do not have any large meaningful effect on the differential STEM outcomes between the low and high dose groups for Cohorts 1 and 2, respectively.

Overall, the hypothesized outcome trends were confirmed. As can be seen in Figures 3 through 7, 13 of the 15 trends (87%) resulted in the hypothesized direction. For STEM PhD, STEM publication, STEM tenure, and STEM occupation, each of the high dose groups earned a higher proportion of a particular outcome than the low dose group. The exception was the reversed trends for STEM patent for Cohorts 1 and 3, although the hypothesized trend was confirmed for Cohort 2.

Proportion Differences and Proportion Ratios

To determine whether the proportion differences between the high and low dose groups within each cohort for each outcome variable was statistically significant, confidence intervals around the difference between proportions and confidence intervals around the ratio of proportions were computed. The results of these analyses (by cohort) can be found in Appendix A. As the sample sizes within each cohort were relatively small for each group, data was aggregated across cohorts in order to uncover more stable results. These combined cohort analyses can be found in Table 6.

In addition to computing the 95% confidence intervals around proportion differences and the relative risk for cohorts combined weighted by N (adding up the numerators and denominators of the proportions across cohorts), I also computed the same statistics combining the cohorts by weighting each proportion equally (adding up the proportions for each cohort and then dividing by three). The results of these analyses were very similar to those in Table 6 and can be found in Appendix B.

As can be seen in Table 6, the confidence intervals around the differences between proportions and around the relative risk were all significant (did not include zero) with the exception of the interval computed for STEM patent. Overall, the pattern of the data found in Figures 3 through 7 combined with the statistical test results found in Table 4 suggest that having a higher, in comparison to a relatively lower, STEM educational dose is associated with a significant difference in the STEM outcomes examined here, even when taking ability into account.

Table 6. Combined Cohort Statistical Analyses for Study 1

	Low Dose	High Dose	95% CI Proportion Differences	Relative Risk	95 % CI Relative Risk
Cohorts Combined (weighted by N)					
STEM PhD	6.17%	11.51%	(0.0245, 0.0823)	1.8654	(1.3204, 2.6356)
STEM Publication	3.75%	8.60%	(0.0238, 0.0730)	2.2907	(1.4830, 3.5385)
STEM Tenure	1.61%	3.33%	(0.0013, 0.0331)	2.0683	(1.0424, 4.1037)
STEM Patent	7.64%	9.85%	(−0.0068, 0.0510)	1.2893	(0.9239, 1.7991)
STEM Occupation	25.74%	32.04%	(0.0167, 0.1093)	1.2447	(1.0588, 1.4631)
At Least One	30.70%	39.53%	(0.0397, 0.1371)	1.2880	(1.1191, 1.4825)

As a further analysis (see Appendix C), I examined the proportion of STEM achievements for groups having low, middle and high levels of STEM Educational dose and the outcome trends were generally aligned with the prior findings examining just two levels of dose (low and high). Appendix D examines the proportion of STEM achievements for groups at every level of STEM Educational dose.

CHAPTER III

STUDY 2: PAINTING A PICTURE OF THE STEM EDUCATIONAL EXPERIENCES OF EXCEPTIONAL STEM ACHIEVERS AMONG TALENT SEARCH PARTICIPANTS AND TOP STEM GRADUATE STUDENTS

Methods

Participants for Study 2

Talent search participants for this study were taken from the SMPY 1972-74 talent search (Cohort 1; SAT-M ≥ 500), SMPY 1976-1978 talent search (Cohort 2; SAT-M ≥ 500), and the SMPY 1980-1983 talent search (Cohort 3; SAT-M ≥ 700). These are the same groups of participants examined in Study 1. In addition, participants for this study also were taken from a 1992survey of top U.S. math and science graduate students (SMPY Cohort 5). Cohort 5 includes first and second year graduate students who were enrolled in the top U.S. STEM programs in 1992 (M = 299, F = 287). They were surveyed at approximately age 25 (Lubinski, Benbow, Shea, Eftekhari-Sanjani, & Halvorson, 2001) and again at approximately age 35 (Lubinski, Benbow, Webb, & Bleske-Rechek, 2006).

This study examines within each cohort the educational profiles of the constituents of educational dose of participants based on five STEM outcomes. That is, whether they have or have not earned STEM PhDs, STEM tenure, STEM publications, STEM patents, and entered a STEM occupation (i.e., STEM PhD vs. no STEM PhD, STEM tenure vs. no STEM tenure, STEM publication vs. no STEM publication, STEM patent vs. no STEM patent, and STEM occupation vs. no STEM occupation). Within each of these two groups for each cohort, I determined the proportion of participants who have had a particular STEM dose component (e.g., STEM special academic training).

For this study, I profiled the STEM educational experiences of Cohort 5 participants that were available to them in a similar way I have done for the other Cohorts (see the STEM dose components for Cohort 5 in Table 7). This is important to determine because there is much talk nowadays about developing and retaining STEM talent without taking into account the dimensions of individuality that are well known to factor into the development of exceptional STEM professionals (Lubinski, Benbow, et al., 2001). One of the contributions of Study 1 was that it was based on three cohorts of mathematically talented participants who possess the mathematical reasoning abilities to excel in STEM. This study (Study 2) includes the cohorts in Study 1 and also a cohort of participants who not only have the ability but also the educational background and training—as well as the abilities, interests, and values—that enabled them to be selected for graduate study at top U.S. STEM programs. These are the participants who made it into the top STEM programs, so it’s important to examine their educational histories. Since there are appreciable numbers of both males and females to make a reliable comparison, I also profiled the experiences by sex. [See Appendix E for an examination the association between STEM Educational Dose and STEM outcomes for the Graduate Student Cohort. Appendix F includes the dose levels for the graduate student males and females combined, males separately, and females separately.]

Table 7. STEM Dose Opportunities Available for Cohort 5

	STEM Dose Component			
	1972-74 Talent Search (Cohort 1)	1976-78 Talent Search (Cohort 2)	1980-83 Talent Search (Cohort 3)	Top STEM Graduate Students (Cohort 5)
Special Academic Training	Yes	Yes	Yes	
College Courses While in High School	Yes	Yes	Yes	Yes
AP or Other Courses for College Credit	Yes	Yes	Yes	Yes
Science Fair/Math Competitions	Yes	Yes	Yes	Yes
Special Classes		Yes	Yes	Yes
Research		Yes	Yes	Yes
Inventions and Projects		Yes	Yes	
Advanced Subject Matter Placement			Yes	
Writing Opportunities			Yes	
Academic Club			Yes	

Anticipated Findings of Study 2

I anticipated that there would be differential proportions for each STEM outcome as a function of having participated in a STEM dose component. I hypothesized that the trends should be fairly consistent throughout (i.e., those earning a particular STEM outcome will have higher proportions having each STEM dose component in comparison to those that did not earn that STEM outcome).

To illustrate graphically the extent to which these hypothesized relationships hold, each contrast is shaded either dark or light gray to form a hit/miss density graph. Dark gray denotes a result in the hypothesized direction, whereas light gray denotes that the hypothesized relationship was falsified. Those regions in the table with data unavailable will be left with ("−") dashes. What was anticipated is a high density dark gray graph indexing the amount of support for the hypothesized relationships, which simultaneously profile the educational histories of all three cohorts. To give readers a more detailed descriptive profile of these educational experiences for each outcome, the percentage of participants in each cell is also provided.

The implications of this analysis, if the hypothesized trends were supported, is that mathematically talented students who have participated in STEM educational opportunities beyond the norm are more likely to achieve STEM outcomes later in life. The same pattern would be anticipated for the STEM graduate students as a whole and STEM graduate student males and females separately. Naturally, these results are suggestive rather than definitive. But as in athletics and music, more opportunities followed by taking advantage of opportunity ("practice") typically results in the development of more expertise and these findings would be in keeping with this idea.

Results

First, let's examine the talent search cohorts. Table 8 includes each of the contrasts for Cohorts 1, 2, and 3. A contrast is colored dark gray if the trend was in the hypothesized direction, and a contrast is colored light gray if the trend was not in the hypothesized direction. Overall, the table is filled primarily with dark gray and less with light gray, illustrating a relatively high density dark gray table. Next, let's examine the STEM graduate student cohort. Table 9 includes each of the contrasts for Cohort 5. Again, overall the table is a relatively high density dark gray table. For the talent search cohorts combined, out of 105 contrasts, 72.4% (76) were in the hypothesized direction and 27.6% (29) were not. For the STEM graduate students, 100% (25) were in the hypothesized direction. Overall, out of 130 total contrasts (Cohorts 1, 2, 3, and 5 combined), 77.7% (101) were in the hypothesized direction and 22.3% (29) were not. So the overall combined group percentages were similar for the talent search cohorts alone, and the talent search cohorts plus the graduate student cohort, however, they were higher for the graduate student cohort alone (see Table 10).

As can be seen in Table 10, when broken down by cohort, it is evident that for Cohorts 1, 2 and 5, the majority of the contrasts were in the hypothesized direction (over 90 percent for each). Also in Table 10, the average difference across all contrasts was computed for each grouping. To compute this, each contrast difference was taken (e.g., the proportion of participants having a STEM dose component who also earned a STEM PhD minus the proportion of participants having a STEM dose component who did not earn a STEM PhD), and then an average of all these differences was computed. For Cohorts 1, 2, and 5, these percentages are 11.1%, 11.8% and 8.48%, all in the hypothesized direction. For Cohort 3, however, although the majority of the contrasts eventuated in the hypothesized direction (54%), this was not appreciably greater than the proportion that did not (46%). In addition, the average difference across all contrasts for Cohort 3 was 1.1%. To take a closer look at Cohort 3, it would make sense to compare the proportion of contrasts in Cohort 3 for the same variables that were also shared by Cohort 2. This analysis also can be found in Table 10, and the proportions remained similar as well as the average difference across all contrasts (0.5%). Therefore it seems that the trends that did not eventuate in the hypothesized direction were primarily concentrated in Cohort 3.

What are some potential explanations? Cohort 5 is a group of individuals specifically selected for having already been granted admission to top U.S. STEM graduate programs. Participants in Cohorts 1 and 2 were selected based on an SAT-M score ≥ 500 in order to focus on those with math ability. Participants from Cohort 3 had a broader range of academic opportunities, and all were participating at high levels. Moreover, advanced intellectual fare for somewhat less profoundly gifted students may not be sufficiently challenging for Cohort 3 participants. Indeed, it seemed that stronger effects are observed for Cohort 3 when the interventions were more tailored to the individual. In Table 8, for example, for those components that were more individualized (i.e., research, inventions and projects, and writing opportunities), 14 of the 15 (93%) trends were in the hypothesized direction. The one contrast that was not in the hypothesized direction was for STEM patent, which seems to be a different phenomenon from the other outcome variables. Therefore, for whatever reason, when restricting the analysis to components that are more tailored to the individual, the trends are in line with those found in the other talent search cohorts and the STEM graduate student sample.

Finally, it is important to investigate within the graduate student sample whether a similar pattern of dose constituent participation holds for both males and females. To demonstrate this would provide support for the idea that STEM talent development occurs similarly for both males and females. This analysis is also shown in Table 9. For Cohort 5 males, 24 contrasts (96%) were in the hypothesized direction and 1 (4%) was not. For Cohort 5 females, however, 19 (76%) were in the hypothesized direction and 6 (24%) were not. However, by looking more closely at the female data, it becomes evident that 4 of the 7 contrasts that resulted in the non-hypothesized direction had proportions that were very close together. Therefore, the average difference across all cohorts might be a more relevant measure of comparison between the males and females. Indeed, for males this percentage was 8.4% and for females it was actually slightly higher at 8.7%. This data suggests that the similarity overall between the top STEM graduate student males and females in the density of their STEM educational experiences beyond the norm.

Table 8. Hit/Miss Density Table Comparing the Proportions of Individuals having a Particular STEM Dose Component Who Had and Who Had Not Earned a Particular STEM Outcome for the Talent Search Participants (Cohorts 1, 2, and 3)

		STEM PhD		STEM Publication		STEM Tenure		STEM Patent		STEM Occupation	
		Y	N	Y	N	Y	N	Y	N	Y	N
Special Academic Training	C1	42.1	38.2	47.4	38	71.4	38	33.3	38.5	41.9	37.1
	C2	80	62.4	78.4	63	90	63.7	75	62.8	66.5	63
	C3	75	77.4	79.4	76.3	72.2	77.2	77.8	76.5	80.9	75
College Courses While in HS	C1	10.5	13.1	15.8	12.9	14.3	13	18.5	12.8	17.8	11.5
	C2	50	27.3	48.6	28.1	50	29.3	42.9	28	32.3	28.4
	C3	40	44.5	41.2	43.7	33.3	44.2	37.8	44.7	39.7	44.9
AP or Other Courses for College Credit	C1	94.7	61.4	78.9	61.8	85.7	62	74.1	61.8	66.5	60.9
	C2	76	61.4	81.1	61.4	80	62.6	67.9	62.3	64.6	62
	C3	61.7	70.1	61.8	68.9	44.4	69.9	57.8	70.4	64.7	69.2
Science Fair/Math Competitions	C1	47.4	31.2	47.4	31.2	71.4	31.2	22.2	31.9	36.6	29.9
	C2	68	62.6	73	62.3	80	62.8	66.1	62.8	60.4	20.5
	C3	65	61	64.7	61.6	66.7	61.7	53.3	64.2	54.4	65.4
Special Classes	C1	-	-	-	-	-	-	-	-	-	-
	C2	34	21.6	21.6	23	40	22.5	28.6	22.1	27.4	20.5
	C3	90	87.2	88.2	87.9	88.9	87.9	88.9	87.7	88.2	87.8
Research	C1	-	-	-	-	-	-	-	-	-	-
	C2	30	9.6	21.6	10.9	10.0	11.8	23.2	10.2	11.0	12.2
	C3	33.3	15.9	41.2	16.8	33.3	19.4	17.8	21.2	23.5	19.2
Inventions and Projects	C1	-	-	-	-	-	-	-	-	-	-
	C2	40	26.9	29.7	28.1	30	28.2	42.9	26.3	29.3	27.7
	C3	86.7	78.7	91.2	78.9	94.4	79.6	88.9	78.8	83.8	79.5
Advanced Subject Matter Placement	C1	-	-	-	-	-	-	-	-	-	-
	C2	-	-	-	-	-	-	-	-	-	-
	C3	28.3	31.7	29.4	31.1	22.2	31.6	37.8	29.1	33.8	29.5
Writing Opportunities	C1	-	-	-	-	-	-	-	-	-	-
	C2	-	-	-	-	-	-	-	-	-	-
	C3	30	21.3	38.2	21.1	44.4	21.8	26.7	22.9	32.4	19.9
Academic Club	C1	-	-	-	-	-	-	-	-	-	-
	C2	-	-	-	-	-	-	-	-	-	-
	C3	10	15.2	11.8	14.2	5.6	14.6	8.9	15.1	13.2	14.1

Table 9. Hit/Miss Density Table for Cohort 5 for Males and Females Combined and Males and Females Separately

Cohort 5 Males and Females	STEM PhD		STEM Publication		STEM Tenure		STEM Patent		STEM Occupation	
	Y	N	Y	N	Y	N	Y	N	Y	N
College Courses While in HS	22.7	12.7	22	14.4	32.3	16.6	18.9	18.6	22.8	17.1
AP or Other Courses for College Credit	55.8	43.6	52.2	49.2	57	49.9	51.6	50.7	61.1	47
Science Fair/Math Competitions	56	38.8	51.6	45.8	49.5	49	52.5	48.3	62.7	44
Special Classes	78.5	62.2	74.4	68.7	82.8	70.2	77.9	70.6	89.6	65.3
Research	22.7	17.2	21.5	19.1	28	19.3	20.5	20.4	24.9	18.8

Cohort 5 Males	STEM PhD		STEM Publication		STEM Tenure		STEM Patent		STEM Occupation	
	Y	N	Y	N	Y	N	Y	N	Y	N
College Courses While in HS	26.5	12.4	26.5	13.4	32.2	18.8	24.3	20.1	22.1	20.5
AP or Other Courses for College Credit	53.8	42.8	52.1	45.9	55.9	48.2	54.3	48.3	62.1	45.1
Science Fair/Math Competitions	55.2	40.7	52.6	45.2	47.5	49.8	55.7	48	61.1	45.4
Special Classes	72.6	62.1	69.7	66.9	81.4	66	71.4	67.8	83.2	63.4
Research	22.4	17.2	22.7	17.2	25.4	19.4	21.4	20.1	23.2	19.4

Cohort 5 Females	STEM PhD		STEM Publication		STEM Tenure		STEM Patent		STEM Occupation	
	Y	N	Y	N	Y	N	Y	N	Y	N
College Courses While in HS	18.5	13	16.8	15.4	32.4	14.4	11.5	17.0	23.5	13.3
AP or Other Courses for College Credit	58	44.5	52.2	52.5	58.8	51.6	48.1	53.1	60.2	49.2
Science Fair/Math Competitions	57	37	50.5	46.3	52.9	48.1	48.1	48.6	64.3	42.3
Special Classes	85	62.3	79.9	70.4	85.3	74.4	86.5	73.5	95.9	67.3
Research	23	17.1	20.1	21	32.4	19.2	19.2	20.7	26.5	18.1

Table 10. Breakdown of the Hit/Miss Density Table by Cohort

	Total # of Contrasts	In Hypothesized Direction	Not in Hypothesized Direction	Average Difference Across All Contrasts (Y minus N)
Cohort 1	20	17 (85%)	3 (15%)	11.1%
Cohort 2	35	32 (91.4%)	3 (8.6%)	11.8%
Cohort 3	50	27 (54%)	23 (46%)	1.1%
Cohort 3 (C2 shared)	35	20 (57.1%)	15 (42.9%)	0.5%
Cohort 5	25	25 (100%)	0 (0%)	8.48%
Cohort 5 Males	25	24 (96%)	1 (4%)	8.4%
Cohort 5 Females	25	19 (76%)	6 (24%)	8.7%
Cohorts 1, 2, and 3	105	76 (72.4%)	29 (27.6%)	6.6%
Cohorts 1, 2, 3, and 5	130	101 (77.7%)	29 (22.3%)	6.94%

CHAPTER IV

DISCUSSION

The Concept of STEM Educational Dose

The general concept of an educational dose—defined as the number of pre-college educational opportunities beyond the norm—was introduced here. As there is much focus on science, technology, engineering and mathematics (STEM) in the current literature and the public press, this general dose concept was focused to include only pre-college STEM educational opportunities beyond the norm. As well, criteria specifically indicative of STEM achievement in adulthood was focused on.

Breaking new ground

The conceptualization of educational dose broadly and STEM educational dose, in particular, is an attempt to go beyond the large body of literature on the topic of educational acceleration. That is, the concept of educational dose considers advanced educational components in combination as a cumulative effect rather than in isolation, believing that it is consistent challenge and the accumulation of educational opportunity that is the critical factor. Prior investigators have compared participants having one educational component to participants not having that component. However, there have been no studies examining educational components as a dose concept as conceptualized here. For example, there have been meta-analytic studies on educational experiences beyond the norm, but the meta-analysis occurs after comparing the group that had experienced a specific educational component to a similar group that did not experience that component (Kulik & Kulik, 1984). The concept of STEM dose examines the combination of STEM components that make up an individual's pattern of taking advantage of advanced or challenging educational components. Next, this conceptualization proposes that the configuration (or pattern/composition of different components) does not matter so much as the number of different components participated in (the dose level). For example, one student might take a STEM college course in high school as well as an AP course and this dose level (in this case a level of 2) could be considered functionally equivalent to that of a student who has STEM special academic training and who participates in STEM research. While it is likely that some interventions are indeed more powerful than others and should carry a greater weight, this issue was not able to be studied within the existing data set. Finally, the outcomes in STEM investigated here as being influenced by educational experiences were variables that have not been examined in prior literature. Of course, all these STEM outcome variables can be considered STEM achievements but they are adult attainments. However, this investigation evaluates not only educational attainment (e.g., earning a PhD) but also creative accomplishments (e.g., publishing a refereed article, inventing a patent, or earning tenure) as well as occupational attainments over 25 years. This investigation thus builds upon the large literature on the topic of educational acceleration and extends the field with a novel concept (educational dose) and its association to rare STEM outcomes achieved decades later.

The Importance of STEM Educational Dose for STEM Achievement

Study 1

This study examined two talent search cohorts in the top 0.5% of math ability (Cohorts 1 and 2) and one talent search cohort in the top 0.01% in math ability (Cohort 3). The concept of STEM dose was assessed by summing the number of different STEM components beyond the norm to index each participant's dose level. In Study 1, within each cohort, participants with a higher STEM dose were compared to participants with a lower STEM dose on the STEM outcomes described prior (PhD, publication, tenure, patent, and occupation). The high and low dose groups within each cohort were constructed using a median split, which was used to determine whether the concept of STEM educational dose is a valid phenomenon. To examine the potential impact of ability, the average SAT-M scores for the low and high dose groups within cohort were computed and the differences between these groups was assessed using independent sample t-tests. For Cohort 1 and 2 the differences were statistically significant, whereas for Cohort 3 the difference was not. Although significance was found for Cohorts 1 and 2 (26 and 24 point SAT-M differences), they may not mean much, as it takes about 170 points on the SAT-M to double the relative risk on earning STEM outcomes within the top 1% of math ability (Wai et al., 2005). Thus ability differences between the high and low dose groups were found to be relatively small and probably inconsequential.

Across all five outcomes (Figures 3, 4, 5, 6, and 7), 86.7% (13 of the 15) of the contrasts resulted in the hypothesized direction. To determine whether participants with a higher compared to a lower dose eventually exhibited significantly more STEM outcomes, 95% confidence intervals around the differences between proportions were utilized. When examining the results with all cohorts combined, the higher dose groups earned significantly more STEM PhDs, STEM publications and more frequently had STEM tenure and a STEM occupation. The exception was STEM patents. The two contrasts that resulted in the non-hypothesized direction (13.3%) were similarly concentrated in Figure 6 (STEM patent). Whereas earning a STEM PhD, a STEM publication, STEM tenure, and entering a STEM occupation are related (e.g., you need to have a STEM PhD and most likely a lot of STEM publications in order to get STEM tenure—which is considered a STEM occupation), patents seem to be a different phenomena. After all, to earn a STEM patent, one is not required to have a STEM PhD (e.g., an engineer with a STEM bachelor's degree—or even no degree at all—can earn a STEM patent). In addition, traditional STEM educational components (such as an AP class) may not be as important for earning a STEM patent. Therefore it would be interesting to investigate what experiences are associated with a greater likelihood of earning a STEM patent.

The relative risk and 95% confidence intervals around the relative risk were also calculated to get a purchase on the practical significance of having a higher compared to a lower STEM educational dose on achieving STEM outcomes. For example, when examining STEM publications in particular, the relative risk is about 2.3 (see Table 6), which means that participants in the high STEM dose group were more than two times as likely to produce a STEM publication as the lower STEM dose group. In a similar vein, when examining the 95% confidence intervals around the relative risk for STEM publications, we can be 95% confident that those in the high STEM dose group are between roughly 1.5 and 3.5 times as likely to earn a STEM publication as those in the lower STEM dose group. Similarly impressive statements can be made for each of the other STEM outcomes in addition to STEM publication. When stated in these terms, the impact of being in the high STEM dose group on producing rare STEM outcomes is apparent. Thus, there seems to be a long-term payoff for being in the higher relative to the lower STEM educational dose group. Value added benefits can be detected.

Study 2

This study examined three talent search cohorts (Cohorts 1, 2, and 3) as well as top STEM graduate students (Cohort 5) and essentially looked at those earning a particular STEM outcome (e.g., STEM PhD) compared to those not earning that STEM outcome (e.g., no STEM PhD) on having participated in the constituents of STEM educational dose. As Cohort 5 is a group selected as top STEM graduate students, they clearly have the requisite ability level as well as the accomplishments and training that enabled them to be selected for these graduate programs. Cohorts 1, 2, and 3 are groups of intellectually talented participants with the requisite ability level and a remarkably similar psychological profile. However, they were not selected on the basis of being in a STEM educational career pattern. Therefore, a comparison of the educational dose constituents of the talent search cohorts and the top STEM graduate student cohort would get at whether the educational constituents (or histories) are similar for individuals within each of these groups who did and did not earn a particular STEM outcome. This would help address generalizability.

Table 8 provides an examination of the talent search cohorts and their educational histories. This table includes 76 (72.4%) total contrasts that resulted in the hypothesized direction (see Table 10). In addition, when looking at the average difference across all contrasts for the talent search cohorts combined, this percentage was 6.6% in the hypothesized direction. However, by examining each of the talent search cohorts in more detail, the picture comes more into focus. For Cohorts 1 and 2, 90% or more of the trends were in the hypothesized direction and the average differences across all contrasts exceeded 11%. For Cohort 3, however, the percentage of trends in the hypothesized direction was only 54% and the average difference across all contrasts was just over 1%. Therefore, Cohort 3 clearly does not exhibit the same pattern as Cohorts 1 and 2.Why might this be the case? One possible reason mentioned earlier might be that Cohort 3 participants had a much broader range of academic opportunities (both STEM and non-STEM related) and essentially all reported several experiences. Both groups (the high and low dose groups within Cohort 3) were highly stimulated. For Cohorts 1 and 2, for example, there were likely only the basic AP courses available, with many of them concentrated in STEM areas, whereas for Cohort 3, since they were identified later, many more AP class options became available by that time and they took advantage of them. For those individuals who did not end up in STEM, since they were so mathematically talented, they were likely to experience many of the STEM dose constituents up through high school. Possibly the reason why we may observe a less consistent pattern in Cohort 3 might be that the STEM dose components examined here were not especially challenging for exceptionally talented students. That is, the typical accelerative fare may simply be not enough for these *profoundly gifted* outliers. Interesting in this regard, those opportunities that were tailored or individualized exhibited stronger effects for Cohort 3, with over 93% of the contrasts in the hypothesized direction (i.e., looking at research, inventions and projects, and writing opportunities).

Table 9 examines the educational histories of the top STEM graduate student sample. 100% of the contrasts resulted in the hypothesized direction, right in line with yet greater than the proportions from Cohorts 1 and 2. It is noteworthy that the overall proportions are similar for two of the talent search cohorts and the graduate student cohort as well as for the individualized experiences for Cohort 3. Nonetheless, the results for Cohort 3 were not as impressive. Therefore the accumulation of educational advantage in STEM is associated with expertise and achievement in STEM as an adult. The data taken as a whole illustrates a generally consistent pattern.

Do these trends hold up for males and females separately? As there are a large number of both males and females in Cohort 5, this question was investigated here, with the results shown in Table 9. For both males (96%) and females (76%), the majority of the contrasts resulted in the hypothesized direction (but 20% less for the females). However, examination of the average difference across all contrasts (M: 8.4%, F: 8.7%) suggests that the overall magnitude of the effect within each of the male and female samples are quite similar. Therefore this provides support for the idea that the educational histories for developing STEM talent seem to be similar for both males and females.

Implications

Overall, the findings discussed here suggest that we should begin to study the concept of educational dose more systematically and empirically to establish its validity for understanding development. If this investigation replicates, the findings would suggest that no single educational opportunity is essential. However, these data do not address whether some components are more powerful or effective than others. These results do imply, however, that it may be beneficial for students who are intellectually mature to have the opportunity to take advantage of higher doses of educational opportunities. Although the analyses conducted here speak specifically to STEM educational dose and STEM achievements, I believe it is reasonable to venture that educational dose applies to other domains as well.

The conceptualization of STEM educational dose also has potential implications for the way educational interventions are viewed. For example, viewing advanced educational components as a buffet of offerings that a student should be allowed to select from based on their intellectual preferences might be beneficial. Educational interventions when viewed in this light are not of the "one size fits all" type, but rather should be tailored to the individual student's taste. In addition, it may be that it does not matter so much what a student does specifically as much as that the student does something to exercise their mind. However, some interventions may be more beneficial.

Limitations and Future Directions

Clearly, one potential limitation of this research is that the dose components were all weighted equally in the indexing of STEM educational dose. Perhaps since some educational components are more “extreme” than others (e.g., having a college course in high school is likely a more intense educational intervention than participating in an academic club), one avenue of future research would be to investigate a way to properly weight the different forms of educational interventions such that the STEM educational dose might take into account these differences in educational component. However, it is difficult to assign very exact weights to match “degrees” of intellectual engagement that an individual experiences when participating in a particular component. For example, one student may take a college course while in high school (e.g., a component that might be considered to be more intense than an AP course on average) yet find that their AP course in the same subject was vastly more stimulating because of the way the material was presented by an outstanding high school teacher or the fellow students in the class. And, we have no measure of the extent to which a particular student engaged with the educational experience. Thus, educational dose as conceptualized and measured in this study is a rough measure.

A future direction for research may be to investigate the impact of a humanities educational dose and its potential impact on humanities achievements when controlling for verbal ability as assessed by the SAT-V. Also, as spatial ability has been neglected and has been demonstrated to be important for STEM areas (e.g., engineering and the physical sciences) and roughly 50% of the top 1% in spatial ability is missed by modern talent searches (Wai, Lubinski, & Benbow, in press), an examination of spatial STEM interventions when controlling for spatial ability is clearly another avenue to pursue. Examining spatial STEM interventions may be especially important for STEM patents, which, as mentioned earlier, might be considered different phenomena from the other

STEM outcome variables examined here. The concept of educational dose needs to be understood better. Research indexing the importance of educational dose in general would also be helpful as well as other studies replicating the findings uncovered in this study by using different educational components to index the educational dose level. It would be important to both replicate the findings uncovered here in a separate sample, as well as attempt to index dose in a variety of contexts to determine the robustness of the concept.

General Discussion

Human capital

The identification and encouragement of human capital is a recent national agenda (Advancing Research in Science and Engineering, 2008; American Competitiveness Initiative, 2006; Asia Society, 2006; Friedman, 2005; National Academy of Sciences, 2005; National Mathematics Advisory Panel, 2008). However, it is also part of a cycle in history that is not new (Flesher & Pressey, 1955; Kulik & Kulik, 1984; Super & Bachrach, 1957; Witty, 1951) and quite likely in many contexts reaches far back in time. As Kulik and Kulik (1984, p. 409) have remarked:

> "American society usually looks upon the academically gifted as a precious resource in times of national threat. In the years immediately following the launching of Sputnik, for example, school systems throughout the country focused their attention on gifted learners, and many schools developed programs to nurture their talents."

In the development of the atomic bomb after the attack on Pearl Harbor, the Korean War, and the race to the moon after Sputnik, the U.S. has succeeded in identifying and developing the human capital in STEM arenas that were necessary for our survival and advancement as a country. Now, with the race for energy independence and our transition into an ideas and knowledge based economy (Friedman, 2008; *The Economist*, 2008), it only makes sense that our country has rediscovered a strong interest in identifying and encouraging human capital. After all, when you really want to win the race, it only makes sense to identify and train the very best human capital that you possess. As Friedman (2008, p. 24) asks his readers in his recent book about a *Hot, Flat, and Crowded* earth:

> "What kind of America would you like to see—an America where there is no big national goal, or a *green America*, where inventing a source of abundant, clean, reliable, cheap electrons, which could enable the whole planet to grow in a way that doesn't destroy its remaining natural habitats, becomes the goal of this generation—inspiring young people to go into math, science, biology, physics, and nanotechnology?"

Or as United States President Barack Obama recently stated in a speech to the National Academy of Sciences (2009), energy is "this generation's greatest project" and that because he didn't want our country to be "out-educated" in STEM, he has sponsored a "$5 billion Race to the Top Program."

Scientific literacy

Another national agenda is the development of scientific literacy. Although scientific literacy of the general population is important, it is quite different from identifying and nurturing STEM leaders (Hattery, 1950, p. 81; Price, 1965). It is right to inspire young people to go into STEM fields as Friedman (2008) and Obama (2009) advocate. However, it is equally important to engender, within the general population, an appreciation for the importance of supporting those that possess the intellectual talent and drive to solve our most critical scientific challenges. However, probabilistically speaking, the handful that does end up solving our energy, economic, and other problems will likely come from the intellectually talented. This can be likened to Allport's (1960, p. 60-61) distinction among "two elites" of college students, the *elite de l'action* (elite of action) and the *elite de la pensee* (elite of thought), where the "creation of the second elite is far more vital for the future of our nation." Linked with what Price (1965) writes, these scientific elite also could be considered groups of what he calls "invisible colleges"(Price & Beaver, 1966):

> "[T]he distribution of scientific effort is such that a very small core of good scientists, long-lived in their efforts, is responsible for the vast majority of scientific work, leaving only a minority of work to be performed by the large bulk of lesser researchers, whose existence is, however, essential to that of the core" (Price, 1965, p. 235).

Today, in the concluding words of the American Academy of Arts and Sciences in regards to STEM creative achievement (2008, p. 45): "The nation faces a thinning of the talent pool on which our future prosperity, health, and security depend." No wonder talent has regained salience.

Choosing to pursue excellence

The United States does face a thinning of the talent pool, but within a group of talented individuals, which ones will choose to pursue excellence and thus be able to solve the pressing technological problems of our society? In addition, how should we encourage and develop such talent? To the extent that one may view educational opportunities or dose as the input, and creativity and eminence (Simonton, 1988, 1994; Zuckerman, 1977) as the output, alongside the fact that scientific excellence requires not just contributions, but consistent contributions over time, it only makes sense that in order to encourage talent development best, it is essential to provide our nation's most talented students with what they want and for what they are ready: To learn the subject matter they are interested in at their desired pace, and in the manner that best suits their individuality.

In the fields of athletics, the arts, and music (and any number of other arenas as well), the pursuit of excellence is a choice (Lubinski & Benbow, 2001; Stanley & Benbow, 1982). And, as professional athletes, artists, or musicians are aware, it is a choice that on average requires over a decade of disciplined and intensive practice (Ericsson, 1996; Simonton, 1988). Field's medalist Terry Tao noted that for being a great mathematician, "Talent is important, of course; but how one develops and nurtures it is even more so." In the field of education, whether a child has advanced educational opportunities or not (and the level of the educational dose they take) is, and should be, a personal decision as well. Stanley (1976, p. 73) has said it best: "It should be no surprise that educational acceleration works well when highly able, splendidly motivated students are given a variety of ways to accomplish it." Put simply, educational interventions work best when they are responsive to the individuality of students (Corno, Cronbach, et al., 2002).For that to occur, our schools and communities must offer varied opportunities to choose among.

It is important to remember that extraordinary development in one area by definition almost precludes exceptional development in many others. In contrast to the emphasis on being a well rounded individual, or to have developed to moderate degrees in many ways, earlier researchers (Tyler, 1974; Wolfle, 1960, 1969) have advocated for diversity within the individual, or the importance of developing in one direction rather than in several[2]. After all, climbing high up one mountain path may prevent you from hiking up many others, but it may afford a view that no other has seen before. So it is with excellence in any field. As James Watson has written: "Being a really good anything—be it university president, violinist, securities lawyer, or a scientist—requires a virtually obsessive devotion to one's objectives. Dividing one's attention [among several] will give the edge to competitors who have the same talent but greater focus" (Watson, 2007, p. 257). These remarks from a scientific champion are echoed by those of an athletic champion—Pete Sampras (2008, p. 18): "In order to be great at something, it really needs to be the focus of your life." Maybe when you have, like Warren Buffett does in business, "a puzzle worth spending a lifetime to solve," developing primarily in one direction is a worthwhile choice (Schroeder, 2008, p. 24).

The conservation of time

Since developing into any kind of champion requires at least a decade of hard work (Ericsson, 1996), would it not make sense to allow students to begin on their path to excellence earlier, before college, if they are ready for it and desire doing so? Pressey (1949) noted 60 years ago that the educational program for many students is already too

[2] Baron-Cohen (2003) gives the example of Richard Borcherds, a Field's Medalist, saying: "He was a master of mathematical judgment, but had hardly left first base in relation to social judgment" (p. 157). Other examples who demonstrated this disconnect between systematizing and empathizing were Nobel Prize winners William Shockley and Paul Dirac (Baron-Cohen, 2003). In a recent article in the *Los Angeles Times* (Magnier, August 10, 2008) an example in great athletic accomplishment was that some of China's Olympic athletes could only read up to the 4th grade level. Although it can be argued that one sided development can be taken to the extreme, oftentimes this diversity within the individual is precisely why great achievement occurs. In the case of Borcherds, Shockley, and Dirac, social skills were likely not very crucial to high achievement in their respective disciplines. In the case of the Chinese athletes, being able to read higher level material was not relevant to their athletic accomplishment (however, it will likely be important *after* they are too old to compete as athletes and need another way to make a living). Maybe for some individual's an unbalanced profile is a worthwhile sacrifice (as in the case of the athletes) or possibly not much of a sacrifice at all (in the case of Borcherds, Shockley and Dirac).

long, and that many students would be better off finishing their education earlier so that they could begin their lives as productive members of society during their years of greatest creativity and productivity (Beard, 1874, 1881; Lehman, 1953; Leshner, 2008; Lowell, 1934; Pressey, 1946b; see van Dalen, 1999, for a discussion of "Beard's Law" regarding the relationship between age and productivity). In regard to STEM in particular, Bill Gates noted in *TheWall Street Journal* that, just as in math and physics, software is a young person's game (Karlgaard, July 28, 2004). Worcester (1956, p. 34) wrote over a half century ago:

> "The time saved by acceleration is important. The amount of knowledge required to do the work of the world today [in 1956] is staggering. Any time saved in getting command of tool subjects and elementary understandings is critically needed for the study of the wider horizons and the more difficult insights at advanced levels. It will mean added time in which higher competencies may be obtained. Society needs this added time. Let us assume that there are 34,000,000 school children in the United States. Ten per cent of these should, according to our evidence, be able to save a year of time. But assume that only three per cent of them could save a year each. Then our country would have gained for its use more than 1,000,000 years of its best brains in a single generation. Don't we need these brains?"

The concept of cumulative advantage

The pursuit of excellence and the saving of time aligns well with the concept of cumulative advantage (Merton, 1968, 1988; Zuckerman, 1977), a version of the Matthew effect, and according to Merton (1988, p. 606) refers to the "processes through which various kinds of opportunities for scientific inquiry as well as the subsequent symbolic and material rewards for the results of that inquiry tend to accumulate for individual practitioners of science." I examined the importance of educational opportunities beyond the norm for learning the scientific-technical subject matter (STEM educational dose), which are included in the concept of cumulative advantage (Walberg & Tsai, 1983; Zuckerman, 1977). This learned (and continually updated) knowledge base serves as the foundation for scientific inquiry.

This conclusion is reinforced by Abelson's (1985, p. 133) independent yet similar message that it is "the *process* through which variables operate in the real world that is important," with one example of a "potentially cumulative" process being "educational interventions." For students who take the appropriate educational dose on a consistent basis, a "ratchet effect" (Duesenberry, 1949) in the accumulation of educational advantage is likely to build significantly over time. Conversely, if students fail to take the appropriate educational dose or are inconsistent in doing so, they may become "caught up in a process of cumulative disadvantage that removes them early on from the system of scientific work and scholarship" (Merton, 1988, p. 615). Indeed, they may not make it into the system at all, being pruned even earlier along the path to scientific achievement.

Concluding Statement

This investigation examined the association between talent search participants having a higher STEM educational dose and a relatively lower STEM educational dose and their later STEM achievements, and the STEM educational histories of talent search and top STEM graduate student participants who had earned one of those STEM achievements (top STEM achievers). Findings support the conclusion that having a higher STEM educational dose is associated with a higher degree of STEM achievements, even when taking ability into account. In addition, top STEM achievers (within the talent search and graduate student samples) are likely to have educational histories that are filled with STEM educational components beyond the norm, and this pattern holds even for the graduate student males and females separately, showing that the educational histories are similar even for each sex. It seems reasonable to suggest that those students with the appropriate level of intellectual maturity and who desire to do so should be allowed to have the opportunity to take a relatively higher dose of STEM educational opportunities. Opportunities for a higher STEM educational dose have a relatively low monetary cost for school districts and parents, as well as a low if any personal cost for students who are prepared for it both emotionally and intellectually. Alongside the potentially high payoff a higher STEM educational dose can have for some students and society, it seems reasonable to suggest that a higher STEM educational dose is something that should be encouraged rather than discouraged for the right individuals. Helping intellectually talented youths who are ready to take a higher dose of STEM educational experiences may help them achieve at their desired level, and what they create and discover may help us all.

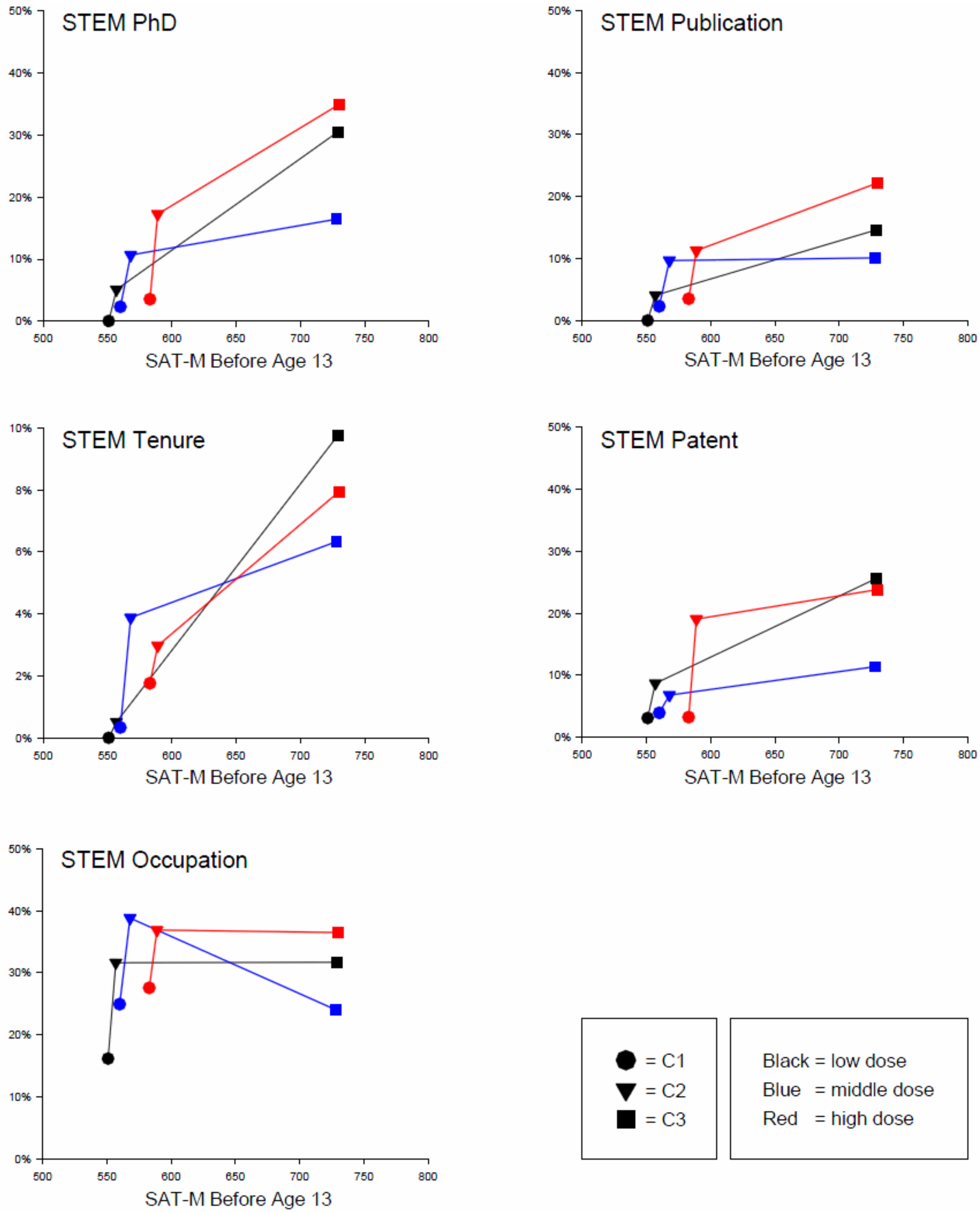
Appendix A. Significance Test Results for Study 1 for Each Cohort

	Low Dose	High Dose	95% CI Proportion Differences	Relative Risk	95 % CI Relative Risk
STEM PhD					
Cohort 1	1.61%	3.52%	(−0.0037, 0.0419)	2.1863	(0.8702, 5.4926)
Cohort 2	5.10%	14.76%	(0.0443, 0.1489)	2.8941	(1.4838, 5.6452)
Cohort 3	25.22%	28.44%	(−0.0832, 0.1476)	1.1276	(0.7314, 1.7384)
STEM Publication					
Cohort 1	1.61%	3.52%	(−0.0037, 0.0419)	2.1863	(0.8702, 5.4926)
Cohort 2	4.08%	10.70%	(0.0201, 0.1123)	2.6225	(1.2254, 5.6119)
Cohort 3	11.30%	19.27%	(−0.0143, 0.1735)	1.7053	(0.8992, 3.2339)
STEM Tenure					
Cohort 1	0.23%	1.76%	(0.0007, 0.0299)	7.6521	(0.9261, 63.2250)
Cohort 2	0.51%	3.32%	(0.0046, 0.0516)	6.5098	(0.8311, 50.9885)
Cohort 3	7.83%	8.26%	(−0.0669, 0.0755)	1.0562	(0.4354, 2.5620)
STEM Patent					
Cohort 1	3.68%	3.23%	(−0.0322, 0.0212)	0.8773	(0.4123, 1.8667)
Cohort 2	8.67%	14.39%	(−0.0002, 0.1146)	1.6597	(0.9681, 2.8453)
Cohort 3	20.87%	19.27%	(−0.1201, 0.0883)	0.9232	(0.5469, 1.5583)
STEM Occupation					
Cohort 1	22.30%	27.57%	(−0.0087, 0.1141)	1.2364	(0.9671, 1.5805)
Cohort 2	31.63%	37.64%	(−0.0269, 0.1469)	1.1896	(0.9205, 1.5372)
Cohort 3	28.70%	32.11%	(−0.0850, 0.1534)	1.1192	(0.7526, 1.6643)
At Least One					
Cohort 1	23.91%	31.67%	(0.0140, 0.1412)	1.3246	(1.0538, 1.6649)
Cohort 2	37.76%	45.39%	(−0.0138, 0.1664)	1.2021	(0.9625, 1.5011)
Cohort 3	44.35%	49.54%	(−0.0786, 0.1824)	1.1170	(0.8452, 1.4764)

Appendix B. Significance Test Results for Study 1 with All Groups Combined and Weighted Equally

	Low Dose	High Dose	95% CI Proportion Differences	Relative Risk	95 % CI Relative Risk
Cohorts Combined (weighted equally)					
STEM PhD	10.64%	15.57%	(0.0062, 0.0924)	1.4633	(1.1191, 1.9130)
STEM Publication	5.66%	11.16%	(0.0192, 0.0906)	1.9717	(1.3785, 2.8201)
STEM Tenure	2.85%	4.44%	(−0.0095, 0.0414)	1.5579	(0.9090, 2.8201)
STEM Patent	11.07%	12.29%	(−0.0285, 0.0529)	1.1102	(0.8379, 1.4708)
STEM Occupation	27.54%	32.43%	(−0.0046, 0.1025)	1.1775	(1.0068, 1.3771)
At Least One	35.34%	42.20%	(0.0188, 0.1184)	1.1941	(1.0494, 1.3588)

Appendix C: Proportions of STEM Achievements for Groups Having Low, Middle, and High Levels of STEM Educational Dose.



Note: The general trend across these panels is that as the dose level increases (from low to middle to high) the percentage earning each particular STEM outcome increases as well. The low, middle, and high STEM dose groups were formed by making the groups as comparable as possible in sample size. Cohort 1 low STEM dose (N = 130, dose level = 0); middle STEM dose (N = 305, dose level = 1); high STEM dose (N = 342, dose level = 2, 3, or 4). Cohort 2 low (N = 196, dose = 0, 1, or 2); middle (N = 103, dose = 3); high (N = 168, dose = 4, 5, 6, or 7). Cohort 3 low (N = 82, dose = 0, 1, 2, 3, or 4); middle (N = 79, dose = 5 or 6); high (N = 63, dose = 7, 8, 9, or 10

Appendix D. *Proportions of STEM Achievements for Groups Having Each Level of STEM Educational Dose*

	STEM PhD			STEM Publication			STEM Tenure			STEM Patent			STEM Occupation		
Dose Level	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3
0	0.00	2.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.08	12.77	0.00	16.15	40.43	0.00
1	2.30	9.26	16.67	2.30	7.41	8.33	0.33	0.00	0.00	3.93	5.56	25.00	24.92	24.07	41.67
2	3.59	4.21	26.32	3.59	4.21	15.79	1.35	1.05	10.53	3.14	8.42	15.79	24.66	31.58	31.58
3	2.06	10.68	34.38	3.09	9.71	15.63	2.06	3.88	9.38	2.06	6.80	34.38	31.96	38.83	31.25
4	9.52	12.90	36.84	4.76	8.60	15.79	4.76	2.15	15.79	9.52	13.98	21.05	38.09	38.71	26.32
5		15.79	12.12		15.79	3.03		3.51	3.03		22.81	9.09		29.82	21.21
6		42.86	19.57		14.29	15.22		7.14	8.70		35.71	13.04		50.00	26.09
7		50.00	38.46		0.00	20.51		0.00	10.26		25.00	23.08		50.00	28.21
8			22.22			27.78			0.00			22.22			55.56
9			66.67			33.33			33.33			33.33			33.33
10			33.33			0.00			0.00			33.33			33.33

Note: Numbers in each cell are percentages (%) of participants at each dose level within cohort that achieved the particular STEM outcome. This table demonstrates that in general, as the dose level increases within each cohort, the percentage of participants earning a particular STEM outcome increases as well.

Appendix E: Proportions of STEM graduate students earning a STEM outcome by dose level.

Graduate Student (Males + Females)	Low Dose	High Dose	95% CI Proportion Differences	Relative Risk	95 % CI Relative Risk
STEM PhD	54.93%	64.94%	(0.0282, 0.1720)	1.1822	(1.0481, 1.3335)
STEM Publication	54.19%	56.82%	(−0.0472, 0.0998)	1.0485	(0.9187, 1.1967)
STEM Tenure	10.59%	16.23%	(0.0055, 0.1073)	1.5326	(1.0482, 2.2405)
STEM Patent	17.49%	16.56%	(−0.0648, 0.0462)	0.9468	(0.6822, 1.3140)
STEM Occupation	21.43%	34.42%	(0.0635, 0.1963)	1.6062	(1.2611, 2.0454)
At Least One	68.97%	85.39%	(0.1044, 0.2240)	1.2381	(1.1430, 1.3411)

Graduate Student (Males)	Low Dose	High Dose	95% CI Proportion Differences	Relative Risk	95 % CI Relative Risk
STEM PhD	56.94%	65.41%	(−0.0151, 0.1845)	1.1488	(0.9757, 1.3526)
STEM Publication	55.02%	60.38%	(−0.0479, 0.1551)	1.0974	(0.9205, 1.3081)
STEM Tenure	13.39%	19.50%	(−0.0158, 0.1380)	1.4563	(0.9124, 2.3245)
STEM Patent	18.18%	20.13%	(−0.0618, 0.1008)	1.1073	(0.7256, 1.6896)
STEM Occupation	21.05%	32.08%	(0.0191, 0.2015)	1.5240	(1.0777, 2.1550)
At Least One	69.86%	85.53%	(0.0739, 0.2395)	1.2243	(1.0972, 1.3662)

Graduate Student (Females)	Low Dose	High Dose	95% CI Proportion Differences	Relative Risk	95 % CI Relative Risk
STEM PhD	52.79%	64.43%	(0.0127, 0.2201)	1.2205	(1.0215, 1.4583)
STEM Publication	53.29%	53.02%	(−0.1089, 0.1035)	0.9949	(0.8147, 1.2149)
STEM Tenure	7.61%	12.75%	(−0.0137, 0.1165)	1.6754	(0.8809, 3.1864)
STEM Patent	16.75%	12.75%	(−0.1146, 0.0349)	0.7612	(0.4513, 1.2839)
STEM Occupation	21.82%	36.91%	(0.0544, 0.2474)	1.6916	(1.2071, 2.3707)
At Least One	68.02%	85.23%	(0.0856, 0.2586)	1.2530	(1.1149, 1.4080)

Appendix F: STEM educational dose level for graduate student males and females combined, males separately, and females separately.

STEM Dose Level	Graduate Student Males + Females	Graduate Student Males	Graduate Student Females
0	150	80	70
1	75	47	28
2	181 (median)	82 (median)	99 (median)
3	187	93	94
4	98	52	46
5	23	14	9

REFERENCES

Abelson, R. P. (1985). A variance explanation paradox: When a little explains a lot. *Psychological Bulletin, 97,* 129-133.

Achter, J. A., & Lubinski, D. (2003). Fostering exceptional development in intellectually talented populations. In W. B. Walsh (Ed.), Counseling psychology and optimal human functioning (pp. 25-54). Mahwah, NJ: Lawrence Erlbaum Associates.

Advancing Research in Science and Engineering. (2008). *Advancing research in science and engineering (ARISE): Investing in early career scientists and high-risk, high-reward research*. Cambridge, MA: American Academy of Arts and Sciences.

Agresti, A. (2002). *Categorical data analysis (2nd Ed.)*. New York: Wiley.

Agresti, A. (2007). *An introduction to categorical data analysis (2nd Ed.)*. New York: Wiley.

Allport, G. W. (1960). Uniqueness in students. In W. D. Weatherford (Ed.), *The goals of higher education*. Cambridge, MA: Harvard University Press.

American Competitiveness Initiative. (2006). *American competitiveness initiative: Leading the world in innovation*. Washington, DC: Domestic Policy Council Office of Science and Technology.

Austin, J. T., & Villanova, P. (1992). The criterion problem: 1917-1992. *Journal of Applied Psychology, 77,* 836-874.

Asia Society (2006). *Math and science education in a global age: What the U.S. can learn from China.* Taken from: http://www.internationaled.org/mathsciencereport.pdf

Ayers, E. (1955). Social attitude toward invention. *American Scientist, 43,* 521.

Baron-Cohen, S. (2003). *The essential difference*. New York: Basic Books.

Beard, G. M. (1874). *Legal responsibility in old age*. New York: Russells.

Beard, G. M. (1881). *American nervousness, its causes and consequences*. New York: Putnam.

Benbow, C. P. (1988). Sex differences in mathematical reasoning ability among the intellectually talented: Their characterization, consequences, and possible explanations. *Behavioral and Brain Sciences, 11,* 169-183.

Benbow, C. P. (1991). Mathematically talented children: Can acceleration meet their educational needs? In N. Colangelo & G. A. Davis (Eds.), *Handbook of gifted education* (2nd Ed., pp. 155-169). Boston: Allyn & Bacon.

Benbow, C. P., & Lubinski, D. (Eds.). (1996). *Intellectual talent: Psychometric and social issues*. Baltimore, MD: Johns Hopkins University Press.

Benbow, C. P., & Lubinski, D. (2006). Julian C. Stanley, Jr. (1918-2005). *American Psychologist, 61,* 251-252.

Benbow, C. P., Lubinski, D., Shea, D. L., & Eftekhari-Sanjani, H. (2000). Sex differences in mathematical reasoning ability: Their status 20 years later. *Psychological Science, 11,* 474-480.

Benbow, C. P., & Stanley, J. C. (Eds.). (1983). *Academic precocity: Aspects of its development*. Baltimore, MD: Johns Hopkins University Press.

Benbow, C. P., & Stanley, J. C. (1996). Inequity in equity: how "equity" can lead to inequity for high-potential students. *Psychology, Public Policy, and Law, 2,* 249-292.

Bleske-Rechek, A., Lubinski, D., & Benbow, C. P. (2004). Meeting the educational needs of special populations: Advanced Placement's role in developing exceptional human capital. *Psychological Science, 15,* 217-224.

Brody, L. E., Assouline, S. G., & Stanley, J. C. (1990). Five years of early entrants: Predicting successful achievement in college. *Gifted Child Quarterly, 34,* 138-142.

Burt, C. (1958). The inheritance of mental ability. *American Psychologist, 13,* 1-15.

Campbell, D. T., & Stanley, J. C. (1963). Experimental and quasi-experimental designs for research on teaching. In N. L. Gage (Ed.), *Handbook of research on teaching*. Chicago: Rand McNally.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Hillsdale, NJ: Erlbaum.

Colangelo, N., & Davis, G. A. (1997). (Eds.), *Handbook of gifted education* (2nd ed.). Boston: Allyn and Bacon.

Colangelo, N., & Davis, G. A. (2003). (Eds.), *Handbook of gifted education* (3rd ed.). Boston: Allyn and Bacon.

Colangelo, N., Assouline, S. G., & Gross, M. U. M. (Eds.) (2004). *A nation deceived: How schools hold back America's brightest students*. Iowa City: University of Iowa.

Cook, T. D., & Campbell, D. T. (1979). *Quasi-experimentation: Design and analysis issues for field studies*. Chicago: Rand McNally.

Corno, L., Cronbach, L. J., et al. (Eds.) (2002). *Remaking the concept of aptitude: Extending the legacy of Richard E. Snow*. Mahwah, NJ: Erlbaum.

Cronbach, L. J. (1957). Two disciplines of scientific psychology. *American Psychologist, 12,* 671-684.

Cronbach, L. J. (1996). Acceleration among the Terman males: Correlates in midlife and after. In C. P. Benbow & D. Lubinski (Eds.). *Intellectual Talent: Psychometric and social issues* (pp. 179-191). Baltimore: Johns Hopkins University Press.

Cronbach, L. J., & Snow, R. E. (1977). Aptitudes and instructional methods: A handbook for research on interactions. New York: John Wiley & Sons.

Duesenberry, J. S. (1949). *Income, savings, and the theory of consumer behavior*. Cambridge, MA: Cambridge University Press.

Ericsson, K. A. (1996). *The road to excellence*. Mahwah, NJ: Erlbaum.

Flesher, M. A., & Pressey, S. L. (1955). Wartime accelerates ten years after. *Journal of Educational Psychology, 46,* 228-238.

Fox, L. H., Brody, L., & Tobin, D. (Eds.). (1980). *Women and the mathematical mystique*. Baltimore: Johns Hopkins University Press.

Friedman, T. L. (2005). *The world is flat: A brief history of the twenty-first century*. New York: Farrar, Straus & Giroux.

Friedman, T. L. (2008). *Hot, flat, and crowded: Why we need a green revolution—and how it can renew America*. New York: Farrar, Straus & Grioux.

Fund for the Advancement of Education. (1957). *They Went to College*. Evaluation Report No. 2, New York City: The Fund.

George, W. C., Cohn, S. J., & Stanley, J. C. (Eds.). (1979). *Educating the gifted: Acceleration and enrichment*. Baltimore, MD: The Johns Hopkins University Press.

Ghiselli, E. E. (1963). Managerial talent. *American Psychologist, 17,* 631-642.

Goddard, H. H. (1930). The gifted child and his education. *NEA Journal, 19,* 275-276.

Goddard, H. H. (1933). The gifted child. *Journal of Educational Sociology, 6,* 354-361.

Goldberg, M. L. (1958). Recent research on the talented. *Teachers College Record, 60,* 150-163.

Guilford, J. P. (1959). Three faces of intellect. *American Psychologist, 14,* 469-479.

Hattery, L. H. (1950). Why waste talent? *School and Society, 71,* 81-84.

Heller, K. A., Mönks, F. J., Sternberg, R. J., & Subotnik, R. F. (Eds.) (2000). *International handbook of giftedness and talent* (2nd Ed.). Oxford, UK: Elsevier.

Hobbs, N. (1951). Community recognition of the gifted. In P. Witty (Ed.), *The gifted child* (pp. 163-183). Boston: Heath.

Hobbs, N. (1958). The compleat counselor. *Personnel and Guidance Journal, 36,* 594-602.

Holahan, C. K., Sears, R. R., & Cronbach, L. J. (1995). *The gifted group in later maturity*. Stanford, CA: Stanford University Press.

Holden, C. (2008). Encourage risk, help young researchers, panel advises. *Science, 320,* 1274.

Hollingworth, L. S. (1926). *Gifted children: Their nature and nurture*. New York: Macmillan.

Hollingworth, L. S. (1939). What we know about the early selection and training of leaders. *Teachers College Record, 40,* 575-592.

Hollingworth, L. S. (1942). *Children above 180 IQ*. New York: World Book.

Humphreys, L. G. (1985). A conceptualization of intellectual giftedness. In F. D. Horowitz & M. O'Brian (Eds.), *The gifted and talented: Developmental perspectives* (pp. 331-360). Washington, DC: APA Press.

Karlgaard, R. (July 28, 2004). Microsoft's IQ dividend. *The Wall Street Journal*. http://online.wsj.com/article/SB109096908950675667.html?mod=todays_us_opinion

Keating, D. P. (Ed.). (1976). *Intellectual talent: Research and development*. Baltimore, MD: The Johns Hopkins University Press.

Keating, D. P., & Stanley, J. C. (1972). Extreme measures for the exceptionally gifted in mathematics and science. *Educational Researcher, 1,* 3-7.

Kulik, J. A., & Kulik, C. C. (1984). Effects of acceleration on students. *Review of Educational Research, 54,* 409-425.

Lehman, H. C. (1953). *Age and achievement*. Princeton, NJ: Princeton University Press.

Leshner, A. I. (2008). Just give them grants. *Science, 320,* 849.

Lowell, A. L. (1934). *At war with academic traditions in America*. Cambridge, MA: Harvard University Press.

Lubinski, D. (2000). Assessing individual differences in human behavior: "Sinking shafts at a few critical points." *Annual Review of Psychology, 51,* 405-444.

Lubinski, D. (2004). Long term effects of educational acceleration. In N. Colangelo, S. Assouline, and M. Gross (Eds.) *A nation deceived: How schools hold back America's brightest students* (Vol II, pp. 23-37). Iowa City, IA: University of Iowa.

Lubinski, D., & Benbow, C. P. (2000). States of Excellence. *American Psychologist, 55,* 137-150.

Lubinski, D., & Benbow, C. P. (2001). Choosing excellence. *American Psychologist, 56*, 76-77.

Lubinski, D., & Benbow, C. P. (2006). Study of Mathematically Precocious Youth after 35 years: Uncovering antecedents for the development of math-science expertise. *Perspectives on Psychological Science, 1,* 316-345.

Lubinski, D., Benbow, C. P., Shea, D. L., Eftekhari-Sanjani, H., & Halvorson, M. B. J. (2001). Men and women at promise for scientific excellence: Similarity not dissimilarity. *Psychological Science, 12,* 309-317.

Lubinski, D., Benbow, C. P., Webb, R. M., & Bleske-Rechek, A. (2006). Tracking exceptional human capital over two decades. *Psychological Science, 17,* 194-199.

Lubinski, D., Webb, R. M., Morelock, M. J., & Benbow, C. P. (2001). Top 1 in 10,000: A 10-year follow-up of the profoundly gifted. *Journal of Applied Psychology, 86,* 718-729.

Lykken, D. T. (1968). Statistical significance in psychological research. *Psychological Bulletin, 70,* 151-159.

MacKinnon, D. W. (1962). The nature and nurture of creative talent. *American Psychologist, 17,* 484-495.

Mackworth, N. H. (1965). Originality. *American Psychologist, 20,* 51-66.

Magnier, M. (August 10, 2008). Pressure to succeed weighs heavily on China's Olympic athletes. *The Los Angeles Times*. http://www.latimes.com/news/nationworld/world/la-fg-psychology10-2008aug10,0,2407785.story

Mangan, K. (June 20, 2008). Northwestern U. law school is latest to introduce 2-year degree. *The Chronicle of Higher Education*. http://chronicle.com/daily/2008/06/3488n.htm

Meehl, P. E. (1978). Theoretical risks and tabular asterisks: Sir Karl, Sir Ronald, and the slow progress of soft psychology. *Journal of Consulting and Clinical Psychology, 46,* 806-834.

Merton, R. K. (1968). The Matthew effect in science. *Science, 159,* 56-63.

Merton, R. K. (1988). The Matthew effect in science, II. *ISIS, 79,* 606-623.

Murray, C. (2008). *Real education: Four simple truths for bringing America's schools back to reality*. New York: Crown Forum.

National Academy of Sciences. (2005). *Rising above the gathering storm*. Washington, DC: National Academy Press.

National Mathematics Advisory Panel (2008). *Foundations for success: The final report of the national mathematics advisory panel*. U.S. Department of Education: Washington, D.C.

Obama, B. (April 27, 2009). Remarks by the President at the National Academy of Sciences annual meeting. http://www.whitehouse.gov/the_press_office/Remarks-by-the-President-at-the-National-Academy-of-Sciences-Annual-Meeting/

Otto, H. J. (1950). Elementary education-III. Organization and administration. In W. S. Monroe (Ed.), *Encyclopedia of Educational Research* (pp. 367-383). New York: Macmillan.

Park, G., Lubinski, D., & Benbow, C. P. (2007). Contrasting intellectual patterns predict creativity in the arts and sciences. *Psychological Science, 18,* 948-952.

Park, G., Lubinski, D., & Benbow, C. P. (2008). Ability differences among people who have commensurate degrees matter for scientific creativity. *Psychological Science, 19,* 957-961.

Paterson, D. G. (1957). The conservation of human talent. *American Psychologist, 12,* 134-144.

Pressey, S. L. (1946a). Acceleration: Disgrace or challenge? *Science, 104*, 215-219.

Pressey, S. L. (1946b). Time-saving in professional training. *American Psychologist, 1,* 324-329.

Pressey, S. L. (1949). *Educational acceleration: Appraisal and basic problems*. Bureau of Educational Research Monographs, No. 31. College of Education, Ohio State University.

Pressey, S. L. (1955). Concerning the nature and nurture of genius. *Scientific Monthly, 81,* 123-129.

Pressey, S. L. (1967). "Fordling" accelerates ten years after. *Journal of Counseling Psychology, 14,* 73-80.

Price, D. J. D. (1965). The scientific foundations of science policy. *Nature, 206,* 233-238.

Price, D. J. D. & Beaver, D. B. (1966). Collaboration in an invisible college. *American Psychologist, 21,* 1011-1018.

Race, H. V. (1918). A study of a class of children of superior intelligence. *The Journal of Educational Psychology, 9,* 91-98.

Rodgers, K. B. (2007). Lessons learned about educating the gifted and talented: A synthesis of the research on educational practice. *Gifted Child Quarterly, 51,* 382-396.

Sampras, P. (2008). *A champion's mind: Lessons from a life in tennis*. New York: Crown Publishers.

Scarr, S. (1992). Developmental theories for the 1990s: Development and individual differences. *Child Development, 63,* 1-19.

Scarr, S. (1996). How people make their own environments: Implications for parents and policy makers. *Psychology, Public Policy, and Law, 2,* 204-228.

Schroeder, A. (2008). *The snowball: Warren Buffett and the business of life*. New York: Bantam Books.

Seashore, C. E. (1909). *Journal of Educational Psychology*.

Seashore, C. E. (1917). *Journal of Applied Psychology*.

Seashore, C. E. (1922). The gifted student and research. *Science, 56,* 641-648.

Seashore, C. E. (1927). *Learning and living in college*. (University of Iowa Studies: Series on Aims and Progress of Research). Iowa City: University of Iowa Press.

Seashore, C. E. (1930). Carl Emil Seashore. In C. Murchison (Ed.), *A history of psychology in autobiography* (Vol. 1, pp. 225-297). Worcester, MA: Clark University Press.

Seashore, C. E. (1942). *Pioneering in psychology*. (University of Iowa Studies, No. 398). Iowa City: University of Iowa Press.

Shadish, W. R., Cook, T. D., & Campbell, D. T. (2002). *Experimental and quasi-experimental designs for generalized causal inference*. Boston: Houghton Mifflin.

Shurkin, J. N. (1992). *Terman's kids: The groundbreaking study of how the gifted grow up*. Boston: Little Brown.

Simonton, D. K. (1988). *Scientific genius*. Cambridge, England: Cambridge University Press.

Simonton, D. K. (1994). *Greatness: Who makes history and why*. New York: Guilford Press.

Snow, C. P. (1967). *The two cultures*. Cambridge, England: Cambridge University Press.

Southern, W. T., & Jones, E. D. (2004). Types of acceleration: Dimensions and issues. In N. Colangelo, S. Assouline, and M. Gross (Eds.) *A nation deceived: How schools hold back America's brightest students* (Vol II, pp. 5-12). Iowa City, IA: University of Iowa.

Southern, W. T., Jones, E. D., & Fiscus, E. D. (1989). Practitioner objections to the academic acceleration of gifted children. *Gifted Child Quarterly, 33,* 29-35.

Stalnaker, J. M. (1961). Recognizing and encouraging talent. *American Psychologist, 16,* 513-522.

Stanley, J. C. (1976). The case for extreme educational acceleration of intellectually brilliant students. *Gifted Child Quarterly, 20,* 65-75.

Stanley, J. C. (1977). Rationale of the Study of Mathematically Precocious Youth (SMPY) during its first five years of promoting educational acceleration. In J. C. Stanley, W. C. George, & C. H. Solano (Eds.), *The gifted and the creative: A fifty year perspective* (pp. 73-112). Baltimore: Johns Hopkins University Press.

Stanley, J. C. (1996). SMPY in the beginning. In C. P. Benbow & D. Lubinski (Eds.), *Intellectual talent: Psychometric and social issues* (pp. 225-235). Baltimore: Johns Hopkins University Press.

Stanley, J. C. (2000). Helping students learn what they don't already know. *Psychology, Public Policy, and Law, 1,* 216-222.

Stanley, J. C., & Benbow, C. P. (1982). Educating mathematically precocious youths: Twelve policy recommendations. *Educational Researcher, 11,* 4-9.

Stanley, J. C., George, W. C., & Solano, C. H. (Eds.). (1977). *The gifted and the creative: A fifty-year perspective*. Baltimore, MD: The Johns Hopkins University Press.

Stanley, J. C., Keating, D. P., & Fox, L. H. (Eds.). (1974). *Mathematical talent: Discovery, description, and development*. Baltimore, MD: The Johns Hopkins University Press.

Steen, L. A. (1988). The science of patterns. *Science, 240,* 611-616.

Strong, E. K. (1958). Satisfactions and interests. *American Psychologist, 13,* 449-456.

Super, D. E., & Bachrach, P. B. (1957). *Scientific careers and vocational development theory*. New York: Bureau of Publications, Teachers College, Columbia University.

Swiatek, M. A., & Benbow, C. P. (1991a). A 10-year longitudinal follow-up of participants in a fast-paced mathematics course. *Journal for Research in Mathematics Education, 22,* 138-150.

Swiatek, M. A., & Benbow, C. P. (1991b). Ten-year longitudinal follow-up of ability matched accelerated and unaccelerated gifted students. *Journal of Educational Psychology, 83,* 528-538.

Taylor, H. (1936). The gifted child and his education. *Journal of Exceptional Children, 3,* 10-14.

Terman, L. M. (1925). *Mental and physical traits of a thousand gifted children: Genetic Studies of Genius, Vol. I*. Palo Alto, CA: Stanford University Press.

Terman, L. M. (1939). The gifted student and his academic environment. *School and Society, 49*, 65-73.

Terman, L. M. (1954). The discovery and encouragement of exceptional talent. *American Psychologist, 9,* 221-230.

Terman, L. M., & Oden, M. H. (1947). *The gifted child grows up. Genetic studies of genius, Vol. IV*. Palo Alto, CA: Stanford University Press.

The Economist. (June 19, 2008). The power and the glory.

Thorndike, E. L. (1911). *Individuality*. Boston: Houghton Mifflin.

Thorndike, E. L. (1939). How may we improve the selection, training, and life-work of leaders? *Teachers College Record, 50,* 593-605.

Tyler, L. E. (1953). *The work of the counselor*. New York: Appleton-Century-Crofts.

Tyler, L. E. (1965). *The psychology of individual differences* (3rd Ed.). New York: Meredith.

Tyler, L. E. (1974). *Individual differences: Abilities and motivational directions*. New York: Meredith.

Van Dalen, H. P. (1999). The golden age of Nobel economists. *American Economist, 43,* 19-35.

Vernon, P. E. (1965). Ability factors and environmental influences. *American Psychologist, 20,* 723-733.

Wai, J., Lubinski, D., & Benbow, C. P. (in press). Spatial ability for STEM domains: Aligning over fifty years of cumulative psychological knowledge solidifies its importance. *Journal of Educational Psychology*.

Wai, J., Lubinski, D., & Benbow, C. P. (2005). Creativity and occupational accomplishments among intellectually precocious youths: An age 13 to age 33 longitudinal study. *Journal of Educational Psychology, 97,* 484-492.

Walberg, H. J., Tsai, S. (1983). 'Matthew' effects in education. *American Educational Research Journal, 20,* 359-373.

Watson, J. D. (2007). *Avoid boring people*. New York: Alfred A. Knopf.

Williamson, E. G. (1939). *How to counsel students*. New York: McGraw-Hill.

Williamson, E. G. (1965). *Vocational counseling: Some historical, philosophical, and theoretical perspectives*. New York: McGraw-Hill.

Witty, P. (1951). *The gifted child*. Boston: Heath.

Witty, P., & Bloom, S. W. (1955). Conserving ability in the sciences. *Exceptional Children, 22,* 10-16.

Witty, P. A., & Wilkins, L. W. (1933). The status of acceleration or grade skipping as an administrative practice. *Educational Administration and Supervision, 19,* 321-346.

Wolfle, D. (1960). Diversity of talent. *American Psychologist, 15,* 535-545.

Wolfle, D. (Ed.) (1969). *The discovery of talent*. Cambridge, MA: Harvard University Press.

Worcester, D. A. (1956). *The education of children of above-average mentality*. Lincoln: University of Nebraska Press.

Zuckerman, H. (1977). *Scientific elite*. New York: Free Press.