

Specialized Public High Schools of Science, Mathematics, and Technology and the STEM Pipeline: What Do We Know Now and What Will We Know in 5 Years?

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Specialized public high schools of science, mathematics, and technology are commonly viewed as the “crown jewel” of their respective school districts and, many times, of their respective states. These schools are intended to coalesce the most academically talented, science-focused students in each district or state and typically draw excellent teachers as well. As the nation considers policies to address Science, Technology, Engineering, and Mathematics (STEM) education issues, options for additional functions are likely to arise. Currently no existing studies provide a comprehensive analysis of the contribution these schools make over and above regular high schools to the STEM pipeline. This article presents the extant literature on variables that have been shown to predict participation in STEM careers on the part of adolescents in and out of specialized high schools. The literature review is followed by a description of a recently embarked 3-year National Science Foundation (NSF)-sponsored study designed to answer the following questions: Are specialized STEM high-school graduates more likely to remain in the STEM pipeline than students with similar achievement and interests who attended regular public high schools? Which educational/instructional practices used by specialized STEM high schools are associated with higher STEM pipeline retention rates in college and higher rates of entrance into STEM-related professions?

Keywords: STEM pipeline, STEM majors, interest and persistence in STEM, talent development, achievement motivation, short-term and long-term program evaluation, cultural values

Front-page news has recently reported on events such as earthquakes, floods and wavering fuel prices. Public discussions of these apparently unrelated events often turn quickly to potential means of mitigating or even avoiding them. Within this discussion, science and technology make up the centerpiece. It is clear that the world often turns to the United States to take the leadership role in science and technology, and it has been a role our nation has accepted and has little intention of ceding. However, in order to maintain our global leadership in science and technology, we must turn to our youth. Among our youth are those with a demonstrated interest in STEM-related fields who will

play a critical role in whether or not our nation retains its leadership role on the cutting edge of science and technology. An important report on the STEM pipeline carried out by Hilton and Lee (1988) two decades ago analyzed students' interest and persistence in science, but did not offer any model for developing this interest. Nor did Hilton and Lee connect early interest to earning degrees associated with STEM-related professions.

The National Mathematics Advisory Panel (NMAP) Final Report entitled *Foundations for Success* (National Mathematics Advisory Panel, 2008) contained the most recent assessment of the United States' standing in STEM disciplines, specifically in mathematics. This report offered a comprehensive review of mathematics education in the United States including content knowledge, pedagogy, teacher education and assessment based on available research and evidence. The opening section of the NMAP report represents the general consensus of the Panel:

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During most of the 20th century, the United States possessed peerless mathematical prowess—not just as measured by the depth and number of the mathematical specialists who practiced here but also by the scale and quality of its engineering, science, and financial leadership, and even by the extent of mathematical education in its broad population. But without substantial and sustained changes to its educational system, the United States will relinquish its leadership in the 21st century. (p. xi)

The development of talent in STEM fields and the ultimate career pathway of gifted STEM students depend on the best available scientific evidence on educational environments that produce sustained interest and motivation for careers in STEM.

Other studies have taken on this task. Evidence from biographical and longitudinal data and expert opinion suggests that adolescents with interests and talents in mathematics and science are more likely to pursue STEM in postsecondary environments when provided with challenging curricula, expert instruction, and peer stimulation (Bloom, 1985; Pyryt, 2000; Subotnik, Duschl, & Selmon, 1993; Tai, Liu, Maltese, & Fan, 2006).

There are many ways of generating these academically stimulating conditions. One increasingly prevalent means is establishing specialized public high schools of science, mathematics and technology. Intuitively, coalescing talented youth interested in science in schools with the faculty and facilities best suited to nurture and challenge their intellectual development seems to be an obvious course of action. However, as with most things, the devil lies in the details. These details include the form and format that these schools should take. Are residential-style high schools more effective than local magnet schools? Are specialized schools-within-schools a more beneficial approach compared to regional centers with classes for a half-day or only a few days a week? The models for structuring specialized STEM high schools vary a great deal. Beyond these issues are other more fundamental questions. Are students who attend specialized STEM high schools more likely to enter STEM-related career fields than those with similar interests and abilities who attended regular high schools? Do specialized STEM high school students hold a broader knowledge base and a different perspective on scientific research and practice that offers them advantages not shared by their peers who attended regular high schools?

WHAT DO WE KNOW NOW?

Fifteen states have developed residential STEM high schools to serve talented adolescents.¹ In addition, large metropolitan areas such as New York and Washington,

¹ The states are (in alphabetical order) Alabama, Arkansas, Georgia, Illinois, Indiana, Kansas, Kentucky, Louisiana, Maine, Mississippi, Missouri, North Carolina, Oklahoma, South Carolina, and Texas.

DC, have organized specialized mathematics and science high schools, some with long traditions such as The Bronx High School of Science, Brooklyn Technical High School, and Stuyvesant High School in New York City. More recent arrivals include Montgomery Blair Science, Mathematics, and Computer Science Magnet Program (Maryland) and Thomas Jefferson High School (Virginia), both established in 1985. The 1980s also heralded a number of state-sponsored residential schools such as the Illinois Mathematics and Science Academy and the North Carolina School for Science and Mathematics. Currently, the spectrum of schools is fairly diverse, with some that are long established and those newly opened, a proportion residential and others with commuting students, some with full-time enrollments and others with part-time enrollments, as well as schools within schools. With this variety of educational models, which works best? The answer to this question is not yet available in the literature.

The theoretical framework for the study being conducted by the authors and described later in this article is Bloom's talent development model. Bloom (1985) conducted a retrospective study of highly accomplished research neurologists and mathematicians. The most important findings addressed the kinds of instruction that contributed most centrally to the participants' talent development. Bloom's three-stage model includes a first teacher or set of teachers who help a young person fall in love with mathematics or science. The second-stage teacher provides instruction on the rules, content, values, and skills that provide access to frontier knowledge in the field. In the course of the second stage, a talented young person begins to identify himself or herself as a novice scientist or mathematician. The third stage of talent development, according to Bloom, is focused on mentored provision of the insider knowledge needed for success in the gifted individual's chosen field.

From what we know, most students enter specialized STEM high schools with interest in science and mathematics, seeking to acquire skills, deeper knowledge and formation of an identity as a young scientist. In the course of their secondary school experience, students are prepared to tackle high-level research questions under the guidance of expert mentors and teachers. It is well known in the specialized high-school community, however, that many students enroll without special interest in STEM subjects or careers. Rather, these students enter such schools seeking a challenging secondary school experience with highly motivated classmates and teachers.

Questions regarding the impact and influence of specialized STEM high schools abound. To date, no large-scale data-based research study has addressed these questions. However, several studies have explored important variables that are associated with retention in the STEM pipeline and we report on them here.

PSYCHOLOGICAL DIMENSIONS

Lubinski and Benbow (2006) and Webb, Lubinski, and Benbow (2002) collected data on 1,110 adults who had participated in the Study of Mathematically Precocious Youth during their adolescence. All participants had scored in the top 1% of the SAT-M before the age of 13 and at age 18 anticipated pursuing a STEM career. According to the researchers, in addition to ability as measured by SAT-M, STEM interests were the best predictors of STEM career participation at age 33. The researchers used (a) the Study of Values (Allport, Vernon, & Lindzey, 1970), (b) Holland's Occupational Codes, (c) advanced high-school coursework, and (d) designation of favorite high-school course to assess their participants' early career interests. Youthful interests explained disparities in employment pursuits between males and females and between those who engaged in STEM-related careers and those who did not.

Specific psychosocial variables may coincide with a child's early interest in the STEM fields. Subotnik, Pillmeier, and Jarvin (in press) applied the Scholarly Productivity/Artistry (SP/A) Model of Talent Development (Subotnik & Jarvin, 2005), first developed for elite musicians, to the development of mathematical giftedness. According to the renowned mathematics scholars who mentor talented youth queried by Subotnik et al. (2009), mathematical cast of mind, persistence through good and bad times, and intrinsic motivation remained constant variables for gifted individuals as they transformed early mathematical abilities into adult creativity. In addition to these constants, during the elementary years, parental support, responsiveness to instruction, and pleasing parents or teachers with successful problem solving are important psychosocial variables. According to the study participants, as adolescents become more expert in mathematics, self-promotion, insider knowledge about the field, and social skills become increasingly influential. Finally, as the young adults move into scholarly careers, psychosocial variables like risk-taking and charisma appeared to be as integral to their mathematical success as early ability or interest in the field.

Yet, what brings young people to commit time and effort to science and mathematics? According to Hannover and Kessels (2004), the answer is, to some degree, how well a student performs in the subject. In addition, Hannover and Kessels argue that students need to be able to match their image of the discipline with their own image. In other words, when choosing to take a course or persisting in a course of study, secondary-school students hold in mind a prototype of a person who is interested or disinterested in the academic subject. They make decisions on likes and the dislikes about academic subjects not only on how well they perform but on how well the prototype person interested in science or mathematics matches with his or her own self-image. The outcomes of the Hannover and Kessels study showed that the student prototypes they collected match stereotypes of science-interested students. That is, science-interested

students are rated lower than others in physical and social attractiveness, social competence, and integration. They are also rated higher in intelligence, motivation, arrogance, and self-centeredness. The authors report that, in general, the prototype of students who like science is less favorably viewed by their peers than those who do not like science. Unless a person has a strong self-image, these prototypes or stereotypes may discourage those with abilities and interests from persisting in STEM subjects. The authors suggested that instructional strategies focusing on creative thinking and discussion in science class may help to reduce these negative associations, and that any opportunities to provide students with stereotype inconsistent experiences can be helpful.

Like Hannover and Kessels (2004), Eccles and Wigfield (1995) studied the relationship between adolescents' achievement-related beliefs and self-perceptions. The Self and Task-Perception Questionnaire employed in their study targeted beliefs and values adolescents hold about mathematics, as well as more general questions about achievement and gender roles. They found a positive relationship between task values and ability perceptions and a negative relationship between those two variables and perceptions of task difficulty. Thus, students were likely to pursue mathematical activities or tasks that they believed they could accomplish well and devalue those activities if they perceived them to be too difficult. The authors determined that adolescents' perceptions of their own abilities were more strongly related to attainment values and interests in the tasks than perceived utility values. Eccles and Wigfield suggested that utility values of mathematics may be influenced more by sociological factors such as culture, gender, etc.

Whereas the above-mentioned scholars focused on early interests in the STEM fields, psychosocial variables related to these early interests, and adolescents' beliefs about science and mathematics, Milgram and Hong (1994); Hong, Whiston, and Milgram (1993); and Livne and Milgram (2000) explored the relationship between out-of-school activities selected by adolescents and adult accomplishment over time. Milgram and Hong argued that out-of-school activities are conducted for pleasure. Therefore, being good at such activities reflects not only talent but task commitment, persistence, and other important personal-social variables. The researchers employed the Tel-Aviv Activities Inventory to catalogue out-of-school activities (Hong et al.) and were able to show that for 35% of the study participants, leisure activities experienced during adolescence were related not only to vocational choice but to the study participants' levels of accomplishment in that vocation.

Previous studies analyzing the development of STEM talent have focused on variables such as demographics, grades in STEM subjects in high school, and standardized test scores in mathematics. Although those variables remain important, the National Science Foundation (NSF)-sponsored study being conducted by the authors will also include

psychosocial variables in order to gain a deeper understanding of participants' attitudes, beliefs, and experiences in STEM subjects. Such variables will include the ages at which participants first became interested in STEM fields, career aspirations, personal motivations for attending their high schools, self-image as a scientist, perceptions of scientists and mathematicians, and STEM-related out-of-school pursuits.

ENVIRONMENTAL DIMENSIONS

Most published evaluation studies of middle- and secondary-school STEM talent initiatives were conducted by program administrators and do not include longitudinal dimensions (Brody, 2006). However, according to Brody, the following elements of successful precollegiate STEM programs stand out both from existing evaluation studies that have been conducted as well as from retrospective studies of practicing scientists: (a) exposure to strong content knowledge in mathematics and science based on academic instruction and hands-on demonstration, (b) appreciation for the utility of STEM subjects in the workplace, (c) role models working in STEM fields, and (d) peers who share interests in STEM.

Brody (2006) further suggested that success of STEM programs may be measured in the short and long term. In the short term, a program's impact could be measured by way of increased exposure to content, raised interest and confidence, and enhanced views of the utility of STEM disciplines on the part of participants. In the longer term, a program would be evaluated based on enrollment and success in advanced courses, selection of STEM majors, awards and recognition, and entry into STEM careers. Finally, some studies might explore the impacts of program participation on eminence in science careers including position status, promotions, honors, publications, and peer recognition.

The ongoing NSF study being conducted by the authors plans to explore the impact of specialized high-school environments by comparing variables such as class dynamics and the degree to which participants considered themselves prepared for university studies (including strong content role models and/or peers in STEM subjects) as compared to a control group who attended regular high schools. Further, participants will be asked to identify their college majors and delineate any awards, publications, or other forms of recognition they may have received. These variables will be developed into questions resembling those from prior survey research (Eccles & Wigfield, 1995; Lee, 1998, 2002; Lubinski & Benbow, 2006; Milgram & Hong, 1994; Miller, Blessing, & Schwartz, 2006; Nauta & Epperson, 2003; Subotnik et al., 1993; Tai et al., 2006; Thomas, 2000). Analysis of these variables will provide a more complete picture of the unique features of environments associated with these specialized schools. The role of these environments on the impact and influence of these high schools should

provide insightful information about what factors make environments most effective for youth talented in STEM.

SOCIOLOGICAL AND CULTURAL DIMENSIONS

In addition to providing high-level content and skills, Ben-David Kolikant and Pollack (2004) argued that courses or programs should be imbued with professional norms to acculturate students into standards of professional practice. In their domain of computer science, they give examples of professional norms and standards such as: "(a) to be intolerant of incorrect programs, (b) to possess the propensity and the ability to perform careful analysis of problems and to provide sound justifications, (c) to appreciate elegant and efficient solutions, and (d) to be self-critical" (citing Hoare, 1989, p. 23). Using explanatory proofs as their *modus operandi*, Ben-David Kolikant and Pollack were able to improve the persistence and the quality of problem solving exhibited in participating high-school computer-science classrooms.

According to Lee (2002), environments that provide emotionally satisfying relationships associated with STEM are more likely to boost girls' retention in STEM majors in college. He cites a notable outcome from Seymour and Hewitt (1997) that documented attrition from science majors in college: female students believed that it was acceptable to leave their science majors, whereas males felt obliged to stick with their earlier decisions. Further, according to Seymour and Hewitt, when women did not establish supportive relationships with faculty, they were more likely to leave STEM. According to Lee, inoculation from STEM attrition in college can result from students' identifying as a scientist, positive relationships with scientists and science students, and support from important others during high school. In other words,

When relationships favor [STEM] involvement, students' selves are organized around [STEM] involvement and the [STEM] behaviors increase. This finding suggests that successful educational communities are places where students can maintain or acquire rewarding social relationships through their involvement in science-related studies. (p. 366)

Another piece by Lee (1998) explored the attitudes and identities of the same cohort of 433 students he worked with above but at the beginning of their STEM summer experience. This study is important because it investigates the central role of interests, how interests can be swayed positively and negatively, and how discrepant new information about science can influence students' sense of identity as "science" or "non-science" persons. In this study, Lee also disaggregates science into the life, natural and social sciences. He gave an example of a student who entered a science program planning

to be a biologist. When the student perceived that the biologists he worked with did not resemble his previously held image of biologists, he changed his field. It was easier for him to change his field of study than to alter his self-image.

High school appears to be a key point at which young people's impressions of science influence their future career decisions. Young women who work closely enough with scientists to view firsthand the lifestyle of women scientists are bound to discover that women scientists in the United States are seriously concerned about combining work and family life (Rosser & Lane, 2002).

Miller et al. (2006) conducted a study of 80 students at a high school affiliated with a southern university. The study sought to examine the courses males and females liked most and least, the majors they aspired to, and their views of science and scientists. Females aspired to people-oriented majors, and this choice was translated into expectations for selecting health careers and hence an interest in biology over other sciences. The authors proposed that to make physical science classes more appealing to females, they could include more discussions of how physics and chemistry contribute to improving the human condition. As a result of their study, Miller et al. also proposed that physical science courses could be taught more passionately and creatively.

Andreescu, Gallian, Kane, and Mertz (2008) researched the low historical participation of females and other minority groups in esteemed international secondary-school mathematics competitions. The authors analyzed complete international data sets of high-school students who had participated in the International Mathematical Olympiad, the U.S.A. Mathematical Olympiad, Mathematical Olympiad Summer Program, and MATHCOUNTS, as well as of college students who had participated in the William Lowell Putnam Mathematical Competition. They compared the low numbers of females on American teams during the past 10 to 20 years versus the numbers of females on other national teams like those from Romania, Bulgaria and Russia. In addition, the authors looked at the number of American winners of these competitions. Compared to international counterparts, American female participation and winnings in these competitions remained quite low. In instances where the U.S. teams did include female winners, many of them were immigrants and had received high-level mathematical instruction in another country before joining the team—or were the daughters of immigrants.

Andreescu et al. (2008) concluded that it was not lack of mathematical skill achieved by American adolescents, but in how the American culture valued and cultivated those skills. Factors such as population size, gross domestic product or per capita income could not readily explain which countries produced top winners, especially female winners, and which countries did not. Instead, "what most of these [winning] countries have in common are rigorous national mathematics curricula along with cultures and educational systems that value, encourage, and support students who excel in

mathematics" (p. 1251). According to Andreescu et al., American sociocultural phenomena such as decreased student popularity associated with mathematical interests, the invisibility of gifted mathematics students' accomplishments on the part of the general public, and insufficient encouragement from teachers or educational institutions were related to the low numbers of American females participating in esteemed international math and science competitions.

From this literature, we hope to explore the following outcomes in our ongoing study: exposure to professional norms, connections to professionals in high school and college, consideration of the impact of science disciplines on the human condition, opportunity to participate in international student competitions, and support from the general public in regards to STEM interests.

EDUCATIONAL DIMENSIONS

In a large sample study of eighth-grade interest in and aspiration to science careers, Tai et al. (2006) were able to demonstrate the relationship between eighth-grade interest and completion of college majors in life or physical sciences. Even taking into account students' academic achievements, demographics, course-taking history, and parents' education levels, those who indicated an interest in biology in eighth grade were 1.9 times as likely to major in biology as those who did not. For physical sciences and engineering the difference was 3.4 times. Of special note, those students with an eighth-grade interest in a science career and average achievement scores in mathematics were more likely to have graduated with a physical science degree than were those with high mathematics achievement and non-science career expectations (34% vs 19%). In other words, roughly half of the students who expected to participate in a science career when they were in eighth grade actually did major in science at the postsecondary level.

Intel® (formerly Westinghouse®) Science Talent Search winners from 1983 were followed longitudinally by Subotnik et al. (1993) to investigate the winners' participation in science 5 years after high-school graduation. By 1988, 41% of the female participants had left science, along with 12% of the males. All but one of those who remained in the science pipeline had been mentored actively, such that they received resources to engage in research as well as the tacit (Wagner & Sternberg, 1986) or insider knowledge needed to succeed. Tacit or insider knowledge in this context incorporates general advice for negotiating effectively within the department, suggestions for good research topics, and introductions to professionals in the discipline. Several of the Intel winners expressed disappointment with the environment they encountered on college campuses. Because of commitments to graduate education, too many of the postsecondary institutions they attended were generally not supportive of

undergraduate placements in research laboratories, particularly on the part of freshmen and sophomores. The contrast was dramatic after working during high school in top laboratories with enthusiastic mentors and teachers. The article also explores whether high schools and other institutions promoting the growth and development of science talent channeled students into name-brand elite institutions rather than those that offered early laboratory experiences and opportunities to work again on the frontiers of science.

Much of the research on educational factors associated with talent development has come from the field of gifted and talented education on topics such as differentiation, grouping, enrichment and acceleration (Moon, Tomlinson, & Callahan, 1995; Reis, Neu, & McGuire, 1997; Tomlinson et al., 2003). Various meta-analyses have been conducted on grouping (C. L. Kulik & J. A. Kulik, 1982; Lou et al., 1996; Rogers, 1991). Yet, these studies did not provide analyses of long-range outcomes or focus on specific educational environments such as specialized high schools.

Research studies on enrichment, which employs greater detail and depth in one or more subjects for gifted students, has shown clear positive effects on student achievement (J. A. Kulik, 1992; Maker & Nelson, 1995; Rogers, 1991). As with differentiation or grouping, these studies focused on immediate student outcomes rather than long-range impact. Furthermore, these studies did not provide a closer look at specialized schools that often utilize enrichment as a major foundation of their curriculum.

Acceleration has been linked to higher student achievement and social adjustment over time (Colangelo, Assouline, & Gross, 2004; J. A. Kulik, 1992; J. A. Kulik & C. L. Kulik, 1984). In addition, NMAP (2008) reported the following:

1. Individualized instruction that allows for the varying of pace produces greater learning outcomes.
2. The research does not indicate that acceleration results in missing knowledge or holes in student knowledge.

Once again, however, the focus of the research has been on general education rather than specialized schools. The current NSF study being conducted by the authors will focus on the particular aspects of these specialized high schools. In addition to interest in the STEM fields (Tai et al., 2006), mentoring, insider knowledge, and laboratory participation (Subotnik et al., 1993), other variables may provide insight into the impact and influence of these schools, such as course content, coursework selection, instructional strategies, and the role of technology.

SPECIALIZED STEM HIGH SCHOOLS

As mentioned previously, many students enroll in specialized high schools based on deep interest in STEM subjects or for

a challenging school experience with motivated classmates and teachers. The impact and influence of these schools is virtually unexplored by any large-scale, data-based study. What does exist is a collection of studies looking at specific variables as they pertain to the science pipeline.

To answer the questions surrounding the apparent crown jewel of a school district and a potential source of talent and workforce development in STEM, a pooling of significant variables that target this student population is necessary. Thus, the current NSF study draws from available instruments mentioned earlier as well as those that follow to identify a comprehensive and thorough set of variables to address the research questions. As discussed, these variables are designed to ensure a holistic look at these talented youth. These variables and the subsequent analysis may provide information necessary for developing and implementing the most effective education setting.

A recent report published by the National Academies Press, *Rising Above the Gathering Storm* (Committee on Prospering in the Global Economy of the 21st Century, 2007), made the claim that, "An effective way to increase student achievement in science and mathematics is to provide an intensive learning experience for high-performing students" (pp. 131–132). The report cites as support for specialized schools an article from the journal *Nature* by Kendall Powell. Initially the citation appears to be on the mark, referencing relevant research:

These schools immerse students in high-quality science and mathematics education, serve as testing grounds for curricula and materials, provide in-classroom educational opportunities for K–12 teachers, and have the resources and staff for summer programs to introduce students to science and mathematics. (p. 132)

However, upon closer examination, this citation references a news article and Powell is identified as a freelance science writer rather than a scholar. His conclusions are drawn in part from interviews of a few graduates from two specialized STEM high schools: Thomas Jefferson High School (Virginia) and the Illinois Mathematics and Science Academy. There are no other citations in Powell's three-page article that offer evidence of the effectiveness of specialized STEM high schools. Thus, an important and influential National Academies Press report pegs some of its hopes for future development of the American STEM workforce on the work of specialized schools, but the leap from evidence to this inference requires the kind of investigation involving a large enough scale and methodological rigor to overcome issues of representativeness and sampling bias.

The first exploratory study of specialized science high schools was reported in 1995 by Feldhusen and Jarwan. Their focus was limited exclusively to predicting the validity of various measures used in admission to residential STEM high-school programs on student success as they matriculated through the program.

A study by Thomas (2000) offered some additional insights. Here the researcher performed a retrospective survey with two analyses comparing graduates from residential and nonresidential specialized STEM high schools. This design included 240 graduates 1 year after matriculation and 178 graduates 4 years after matriculation. Most salient to the study discussed in this article are the results from the high school-plus-4-year cohort. Thomas compared the percentage of 1995 specialized high-school graduates who reported that they majored in math/computer science or science compared to national percentages of college majors collected by the National Center for Education Statistics in 1992–1993. Whereas 3% of college graduates majored in math/computer science nationally, 10% of specialized high-school graduates did. Most notably, 51% of specialized high-school students reported majoring in science, whereas 23% of the national sample graduated with such majors. Ten specialized STEM high schools participated in this study—5 residential and 5 nonresidential, and outcomes were not different based on this distinction. The study that will be conducted by the authors will scale up and address the broad impacts of specialized STEM high schools with larger sample sizes and a comparison group of high-achieving students who did not attend specialized high schools. Though we intuit that these specialized schools are highly effective, we contend that some models (e.g., residential, nonresidential) or instructional variables are likely to be more effective than others. We argue that the underlying sources of these more effective models or variables should be uncovered and proliferated among other specialized STEM high schools, as well as with special programs offered at public and private high schools serving interested and talented youth.

WHAT WILL WE KNOW IN 5 YEARS?

Since 1988, the 15 founding member schools in the National Consortium of Specialized Secondary Schools of Mathematics, Science, and Technology (NCSSSMST) have been joined by over 90 other schools, a sixfold increase in membership over a period of 20 years. Clearly, the expansion in the number of specialized STEM schools applying a wide variety of educational models begs the question of which or what is best. Here, the paucity in existing research offers an opportunity to address two pressing questions about the form and format of specialized STEM high schools:

1. Are graduates from specialized STEM high schools more likely to enroll in STEM-related studies and career fields when compared with graduates from regular nonmagnet, nonexamination high schools with comparable academic and demographic backgrounds?

2. What school models employed by specialized STEM high schools are most associated with entrance into STEM-related studies and career fields? (School models include residential schools, schools-within-schools, regional centers with half-day courses.)

Contributing to the relevance and pressing nature of these questions is the legislative activity in response to key reports such as *Rising Above the Gathering Storm* (Committee on Prospering in the Global Economy, 2007). President George W. Bush signed the America COMPETES Act into law on August 9, 2007, to support additional initiatives to improve the nation's competitiveness including funding authorizations to states to seed additional specialized high schools. Each year, states and districts add new specialized STEM high schools to their systems. For example, 20 STEM high schools opened during the 2005–2006 school year and another 12 were proposed for 2007–2008.²

Despite the growing numbers of specialized STEM high schools, student access is not widely available. According to Subotnik, Edmiston, and Rayhack (2007), access to STEM schools is geographically uneven. Only 27 out of 50 states offer STEM talent programs such as regional centers, magnet schools, governor schools, or exam schools. A select few of these states have five or more programs: Georgia (8 schools), Maryland (5 schools), Michigan (10 schools), Virginia (9 schools), New Jersey (8 schools), and New York (7 schools). Many other states with similar population sizes do not offer any such educational opportunities.

Given the push to create additional schools, it seems imperative that “best practice” with regard to specialized STEM high schools be identified in a scientifically robust manner.

The authors are in the midst of conducting a 3-year study on the contributions made by specialized public high schools to the development of scientific researchers in the life, physical, and behavioral sciences. The research method we are employing includes a national survey of 5,000 specialized public STEM high-school graduates who completed their secondary education within the last 4 to 6 years. Those responses will be compared with responses from 1,000 similarly talented participants of the Midwest Academic Talent Search who graduated from traditional high schools in the last 4–6 years. These analyses have the potential to inform policies leading to the construction of the most effective schools within the means of each district or state. Non-bricks-and-mortar-type educational programs such as the Midwest Academic Talent Search (MATS) offer a good comparison group to some specialized STEM school models. Study outcomes could imply that the MATS

² Data derived from <http://nces.ed.gov/ccd/commonfiles/stateresults.asp> as part of the Common Core of Data, Institute of Education Science, National Center for Education Statistics.

programmatic approach, in conjunction with regular school programs, offers the best investment for districts with limited means to address the needs of their gifted and talented students. In all likelihood, any research results will be mixed, offering findings that require careful translation into policy.

Public education in the United States has often been highlighted by expansive policies and trends, beginning with the progressive movement sparked by the ideas and ideals of John Dewey. Given current educational trends and policy decisions, it appears that today's educational climate may come to be known as the Age of Evidence and Accountability. Despite the ambiguity that has often surrounded public policy with regard to gifted and talented education, what is clear is that whatever efforts are undertaken, questions will be asked regarding the outcomes of these efforts and what evidence is being used to draw these conclusions. Analyses using large-scale sampling have the potential to (a) provide insights into the contributions made by specialized schools to the STEM pipeline and to STEM literacy in advanced professions; and, for the first time, (b) offer evidence-based best practices to inform the establishment of new specialized STEM schools as well as the formulation of other STEM-related policy at local, state, and national levels.

However, specialized STEM high schools need to continue their own efforts to chronicle their practices and the outcomes these practices have led to. It is precisely these types of efforts carried out by NCSSMST (see for example, Thomas, 2000) and by individual schools that will become the items cited when the public focus is aimed at specialized STEM high schools. As with any inoculation, proactive efforts to analyze policies and practices at school and classroom levels in order to guide educational practice may lead to self-revelation and self-criticism. Any discomfort that arises from such self-evaluation will pale in comparison to imminent criticisms from school boards and politicians seeking to cut budgets and garner public attention for their efforts to "fix" education and promote "equity." In the end, the focus should not be on supporting any given practice but rather on producing evidence that would lead to the best and most cost-effective educational practice, the type of practice with the integrity to stand up to the harsh light of public scrutiny.

Advocacy has often taken the place of research in education. Given the attractive and intuitively persuasive arguments set forth by education advocates in the past, coupled with the challenges faced in collecting the rigorous data necessary to carry out a thorough analysis, it is no small wonder that the difference between advocacy and research has been obscured. The difference will become the subject of much attention in the future and any efforts beginning now to understand these differences will in all likelihood pay dividends to those willing to make the investment. It is

with this concern in mind that studying the impact of specialized STEM high schools has so much to offer both the gifted education community and the wider educational establishment.

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REFERENCES

- Allport, G. W., Vernon, P. E., & Lindzey, G. (1970). *Manual: Study of values* (3rd ed.). Boston: Houghton Mifflin.
- America COMPETES Act, H. R. 2272 110th Congress (2007).
- Andreescu, T., Gallian, J. A., Kane, J. M., & Mertz, J. E. (2008). Cross-cultural analysis of students with exceptional talent in mathematical problem-solving. *Notices of the American Mathematical Society*, 55(10), 1248-1260.
- Ben-David Kolikant, Y., & Pollack, S. (2004). Establishing computer science professional norms among high school students. *Computer Science Education*, 14(1), 21-35.
- Bloom, B. S. (Ed.). (1985). *Developing talent in young people*. New York: Ballantine Books.
- Brody, L. (2006, September). *Measuring the effectiveness of STEM talent initiatives for middle and high school students*. Paper presented at the meeting of the National Academies Center for Education, in collaboration with the American Psychological Association, U.S. Department of Education, National Institutes of Health, National Science Foundation, and National Commission on Teaching and America's Future, Washington, DC. Retrieved November 12, 2009, from <http://www7.nationalacademies.org/cfe/Linda%20Brody%20Think%20Piece.pdf>
- Colangelo, N., Assouline, S. G., & Gross, M. U. M. (Eds.). (2004). *A nation deceived: How schools hold back America's brightest students* (Vol. 2). Iowa City: University of Iowa, the Connie Belin & Jacqueline N. Blank International Center for Gifted Education and Talent Development.
- Committee on Prospering in the Global Economy of the 21st Century: An Agenda for American Science and Technology; Committee on Science, Engineering and Public Policy; National Academy of Sciences; National Academy of Engineering; & Institute of Medicine. (2007). *Rising above the gathering storm: Energizing and employing America for a brighter economic future*. Washington, DC: The National Academies Press.
- Eccles, J., & Wigfield, A. (1995). In the mind of the actor: The structure of adolescents' achievement task values and expectancy-related beliefs. *Personality and Social Psychology Bulletin*, 21(3), 215-225.
- Feldhusen, J. F., & Jarwan, F. (1995). Predictors of academic success at state-supported residential schools for mathematics and science: A validity study. *Educational and Psychological Measurement*, 55(3), 505-512.
- Hannover, B., & Kessels, U. (2004). Self-to-prototype matching as a strategy for making academic choices. Why high school students do not like math and science. *Learning and Instruction*, 14, 51-67.
- Hilton, T. L., & Lee, V. E. (1988). Student interest and persistence in science: Changes in the education pipeline in the last decade. *Journal of Higher Education*, 59, 510-526.
- Hoare, C. A. R. (1989). Computer science. In C. A. R. Hoare & C. B. Jones (Eds.), *Essays in computing science* (pp. 89-101). Englewood Cliffs, NJ: Prentice Hall.

- Hong, E., Whiston, S. C., & Milgram, R. M. (1993). Leisure activities in career guidance for gifted and talented adolescents: A validation study of the Tel-Aviv Activities Inventory. *Gifted Child Quarterly*, 37, 65–68.
- Kulik, C. L., & Kulik, J. A. (1982). Effects of ability grouping on secondary school students: A meta-analysis of evaluation findings. *American Educational Research Journal*, 19, 415–428.
- Kulik, J. A. (1992). *An analysis of the research on ability grouping: Historical and contemporary perspectives*. Storrs: University of Connecticut, National Research Center on the Gifted and Talented.
- Kulik, J. A., & Kulik, C. L. (1984). Effects of accelerated instruction on students. *Review of Educational Research*, 54, 409–425.
- Lee, J. D. (1998). Which kids can “become” scientists? Effects of gender, self-concepts, and perceptions of scientists. *Social Psychology Quarterly*, 61, 199–219.
- Lee, J. D. (2002). More than ability: Gender and personal relationships influence science and technology involvement. *Sociology of Education*, 75, 349–373.
- Livne, N. L., & Milgram, R. M. (2000). Assessing four levels of creative mathematical ability in Israeli adolescents utilizing out-of-school activities: A circular three-stage technique. *Roeper Review*, 22, 111–116.
- Lou, Y., Abrami, P., Spence, J., Poulsen, C., Chambers, B., & d’Apollonia, S. (1996). Within-class grouping: A meta-analysis. *Review of Educational Research*, 66, 423–458.
- 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.
- Maker, C. J., & Nelson, A. B. (1995). *Teaching models in education in the gifted* (2nd ed.). Austin, TX: Pro-Ed.
- Milgram, R. M., & Hong, E. (1994). Creative thinking and creative performance in adolescents as predictors of creative attainments in adults: A follow-up study after 18 years. In R. F. Subotnik & K. D. Arnold (Eds.), *Beyond Terman: Contemporary longitudinal studies of giftedness and talent* (pp. 212–228). Norwood, NJ: Ablex.
- Miller, P. H., Blessing, J. S., & Schwartz, S. (2006). Gender differences in high school students’ views about science. *International Journal of Science Education*, 28, 363–381.
- Moon, T., Tomlinson, C. A., & Callahan, C. (1995). *Academic diversity in the middle school: Results of a national survey of middle school administrators and teachers* (Research Monograph 95124). Charlottesville: University of Virginia, National Research Center on the Gifted and Talented.
- National Mathematics Advisory Panel. (2008). *Foundations for success: The final report of the National Mathematics Advisory Panel*. Washington, DC: U.S. Department of Education.
- Nauta, M., & Epperson, D. (2003). A longitudinal examination of the social-cognitive model applied to high school girls’ choice of nontraditional college majors and aspirations. *Journal of Counseling Psychology*, 50, 448–457.
- Pyryt, M. C. (2000). Talent development in science and technology. In K. A. Heller, F. J. Monks, R. J. Sternberg, & R. F. Subotnik (Eds.), *International handbook of giftedness and talent* (2nd ed., pp. 427–437). Oxford, England: Elsevier.
- Reis, S., Neu, T., & McGuire, J. (1997). Case studies of high-ability students with learning disabilities who have achieved. *Exceptional Children*, 63, 463–479.
- Rogers, K. B. (1991). *The relationship of grouping practices to the education of the gifted and talented learner*. Storrs: University of Connecticut, National Research Center on the Gifted and Talented.
- Rosser, S. V., & Lane, E. O. (2002). Key barriers for academic institutions seeking to retain female scientists and engineers: Family-unfriendly policies, low numbers, stereotypes, and harassment. *Journal of Women and Minorities in Science and Engineering*, 8, 163–191.
- Sable, J., Gaviola, N., Garofano, A., & Sietsema, J. (2007, June). Documentation to the NCES common core of data public elementary/secondary school universe survey: School year 2005–2006. Washington, DC: United States Department of Education. Retrieved November 12, 2009, from <http://nces.ed.gov/ccd/pdf/psu051agen.pdf>
- Seymour, E., & Hewitt, N. M. (1997). *Talking about leaving: Why undergraduates leave the sciences*. Boulder, CO: Westview Press.
- Subotnik, R. F., Duschl, R., & Selmon, E. (1993). Retention and attrition of science talent: A longitudinal study of Westinghouse Science Talent Search winners. *International Journal of Science Education*, 15(1), 61–72.
- Subotnik, R. F., Edmiston, A. M., & Rayhack, K. M. (2007). Developing national policies in STEM talent development: Obstacles and opportunities. In P. Cserehely, K. Korlevic, & K. Sulyok (Eds.), *Science education: Models and networking of student research training under 21: Vol 16. NATO security through science series: Human and societal dynamics* (pp. 28–38). Amsterdam: IOS Press.
- Subotnik, R. F., Pillmeier, E., & Jarvin, L. (2009). The psychosocial dimensions of creativity in mathematics: Implications for gifted education policy. In R. Leikin, A. Berman, & B. Koichu (Eds.), *Creativity in mathematics and the education of gifted students* (pp. 165–180). Rotterdam, The Netherlands: Sense Publishers.
- Tai, R. H., Liu, C. Q., Maltese, A. V., & Fan, X. (2006). Planning early for careers in science. *Science*, 312(5777), 1143–1144.
- Thomas, J. (2000). First year findings: NCSSMST longitudinal study. *NCSSMST Journal*, 5(2), 4–5.
- Tomlinson, C. A., Brighton, C., Hertberg, H., Callahan, C. M., Moon, T. R., Brimjoin, K., et al. (2003). Differentiating instruction in response to student readiness, interest, and learning profile in academically diverse classrooms: A review of literature. *Journal for the Education of the Gifted*, 27, 119–145.
- Wagner, R. K., & Sternberg, R. J. (1986). Tacit knowledge and intelligence in the everyday world. In R. J. Sternberg & R. K. Wagner (Eds.), *Practical intelligence: Nature and origins of competence in the everyday world* (pp. 51–83). New York: Cambridge University Press.
- Webb, R. W., Lubinski, D., & Benbow, C. P. (2002). Mathematically facile adolescents with math-science aspirations: New perspectives on their educational and vocational development. *Journal of Educational Psychology*, 94, 785–794.

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