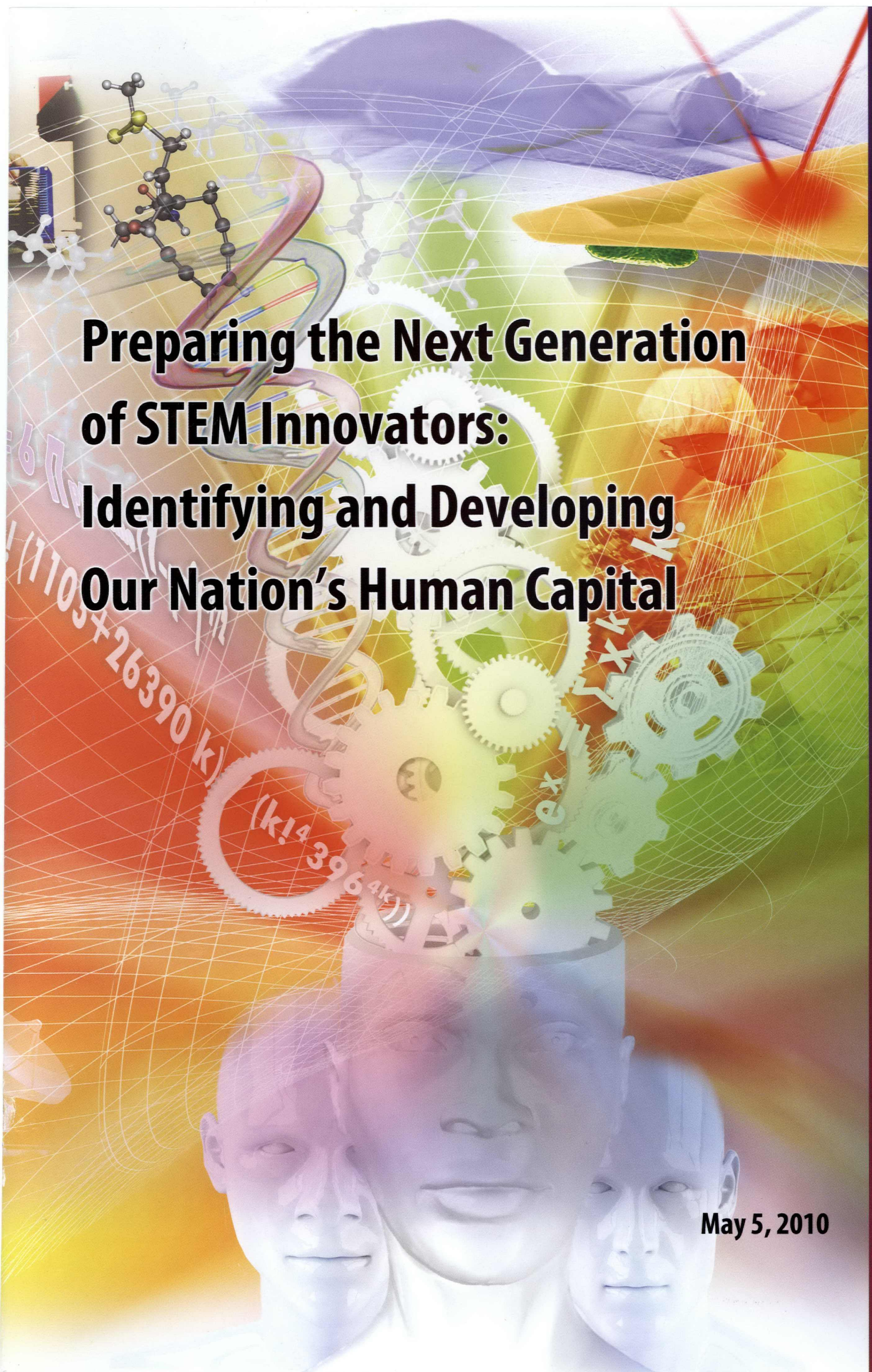

Preparing the Next Generation of STEM Innovators: Identifying and Developing Our Nation's Human Capital

May 5, 2010

NATIONAL SCIENCE BOARD

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Information Dissemination Branch, National Science Foundation

NSB-10-33

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National Science Board

May 5, 2010

MEMORANDUM FROM THE CHAIRMAN OF THE NATIONAL SCIENCE BOARD

SUBJECT: *Preparing the Next Generation of STEM Innovators: Identifying and Developing our Nation's Human Capital*

Scientific and technological innovation continues to play an essential role in catalyzing the creation of new industries, spawning job growth, and improving the quality of life in the United States and throughout the world. Innovation relies, in part, on individuals possessing the knowledge, skills, creativity, and foresight to forge new paths. The National Science Board (Board) is pleased to present its recommendations on how to support the identification and development of talented young men and women who have the potential to become our Country's next generation of science, technology, engineering, and mathematics (STEM) innovators.

The Board embarked on this detailed study for two mutually reinforcing reasons:

1. The long-term prosperity of our Nation will increasingly rely on talented and motivated individuals who will comprise the vanguard of scientific and technological innovation; and

2. Every student in America deserves the opportunity to achieve his or her full potential.

This report contains a series of policy actions, a research agenda, and three key recommendations detailing how our Nation might foster the identification and development of future STEM innovators. This report draws on the findings from an expert panel discussion held at the National Science Foundation (NSF) on August 23-25, 2009, and a 2-year examination of the issue by the Board with the support of expert staff from the NSF Directorate for Education and Human Resources and the U.S. Department of Education.

The Board firmly believes that the recommendations set forth in this report will help ensure a legacy of continued prosperity and will engender a renewed aspiration towards equity *and* excellence in U.S. STEM education.

Steven C. Beering

Steven C. Beering
Chairman

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ACKNOWLEDGMENTS

The National Science Board (Board) appreciates the numerous individuals who contributed to the work of the Board's Committee on Education and Human Resources and the *ad hoc* Task Group on STEM Innovators. A list of distinguished panelists and discussants who participated in the August 2009 expert panel discussion and provided significant input into the development of the report is provided in Appendix II.

We are particularly indebted to Dr. Cora B. Marrett, Acting Deputy Director of the National Science Foundation (NSF), and the following NSF staff members in the Directorate for Education and Human Resources for assistance in planning the expert panel discussion and/or providing input during the development of the report: Drs. Myles Boylan, Alphonse DeSena, Janice Earle, Joan Ferrini-Mundy, Ping Ge, James E. Hamos, Karen Oates, Ginger Holmes Rowell, and Larry E. Suter. The Board would like to acknowledge the efforts of Ms. Patricia Johnson, U.S. Department of Education, for assistance in planning the expert panel discussion, serving as a panelist, and reviewing several drafts of the report. The Board would like to thank several external experts who provided a critical reading of the report draft: Drs. Linda E. Brody, Carolyn M. Callahan, Nancy Green, Sidney Moon, Paula Olszewski-Kubilius, Sally M. Reis, Nancy M. Robinson, and Mark Saul.

The National Science Board Office (NSBO) provided essential support to the work of the Task Group on STEM Innovators. Especially deserving of recognition are: Dr. Matthew Wilson, AAAS Science and Technology Policy Fellow and NSBO staff lead for the STEM Innovators project, for his thoughtful and diligent work throughout the duration of this initiative; Mses. Jennie Moehlmann and Jean Pomeroy, for policy guidance and critical review of numerous drafts of the report; Ms. Jennifer Richards, for editorial support throughout the drafting process; Mses. Betty Wong, Pamela McKinley, and Kyscha Slater-Williams, for providing administrative support for the expert panel discussion; and Mses. Ann Ferrante and Kelly DuBose for editorial and publishing assistance. Lastly, Dr. Craig R. Robinson, Acting Executive Officer of the Board and Board Office Director, provided essential guidance and support throughout the duration of the project.

PROCESS FOR PRODUCING THE REPORT

The National Science Board (Board) has long been concerned with the state of science, technology, engineering, and mathematics (STEM) education in the United States. In October 2007, the Board asserted in its *National Action Plan for Addressing the Critical Needs of the U.S. Science, Technology, Engineering and Mathematics Education System* (STEM Action Plan, NSB-07-114) that the Nation must enhance its "ability to produce a numerate and scientifically and technologically literate society and to increase and improve the STEM education workforce." In that report and others (e.g., *The Science and Engineering Workforce: Realizing America's Potential*, NSB-03-69), the Board acknowledged that the United States has become increasingly dependent on importing STEM talent from other countries, rather than expanding the STEM pipeline from our own domestic talent pool. In this report, the Board addresses the educational needs of our Nation's most talented and motivated students, who have the potential to become high-achieving members of the U.S. STEM workforce, or STEM innovators. **STEM "innovators" are defined as those individuals who have developed the expertise to become leading STEM professionals and perhaps the creators of significant breakthroughs or advances in scientific and technological understanding.** To this end, this report addresses talent identification and development of children and young adults, and provides recommendations that should ultimately enhance the innovation capacity of our Nation.

To produce this report, the Board charged the Committee on Education and Human Resources to form an *ad hoc* Task Group on STEM Innovators in August 2008 (see Appendix I). The *ad hoc* Task Group was directed to identify strategies for increasing the number of future STEM innovators and synthesize recommendations for how the National Science Foundation (NSF), and possibly other Federal entities, might engage in fostering the development of these individuals. This report and the recommendations set forth herein are based on the findings from an expert panel discussion held on August 23-25, 2009 (see Appendix III), and a 2-year examination of the issue by the *ad hoc* Task Group with the support of experts from the NSF Directorate for Education and Human Resources and the U.S. Department of Education.

EXECUTIVE SUMMARY

On November 17, 1944, in the midst of World War II, President Franklin Delano Roosevelt wrote a letter to Vannevar Bush, head of the U.S. Office for Scientific Research and Development. In that letter, President Roosevelt posed the question:

> *Can an effective program be proposed for discovering and developing scientific talent in American youth so that the continuing future of scientific research in this country may be assured on a level comparable to what has been done during the war?*[1]

In *Science–The Endless Frontier*, Vannevar Bush offered his answer to this question. In his response, Bush called for the renewal of our scientific talent through the U.S. education system. He wrote:

> *The responsibility for the creation of new scientific knowledge rests on that small body of men and women who understand the fundamental laws of nature and are skilled in the techniques of scientific research. While there will always be the rare individual who will rise to the top without benefit of formal education and training, he is the exception and even he might make a more notable contribution if he had the benefit of the best education we have to offer.*[2]

A little more than a decade later, mobilized by the Soviet's successful launch of Sputnik, the United States embarked on a collective, coordinated, and sustained effort to recruit and educate the "best and brightest" who subsequently would form a new generation of leaders and innovators in science and engineering. This effort resulted in unprecedented scientific and technological progress, leading to the creation of new enterprises, new jobs, and the betterment of the national standard of living. At the root of this progress was a substantial investment in research and development, along with a nationwide focus on excellence in science, technology, engineering, and mathematics (STEM) education and talent development. Regrettably, by the 1970s, this national sense of urgency had diminished, and complacency soon supplanted the ideal of excellence in education. Today, faced with growing international competition, the cost of inaction continues to grow at an intensifying pace.

The National Science Board (Board) firmly believes that to ensure the long-term prosperity of our Nation, we must renew our collective commitment to excellence in education and the development of scientific talent. Currently, far too many of America's best and brightest young men and women go unrecognized and underdeveloped, and, thus, fail to reach their full potential. This represents a loss for both the individual *and* society. The Nation needs "STEM innovators"—those individuals who have developed the expertise to become leading STEM professionals and perhaps the creators of significant breakthroughs or advances in scientific and technological understanding. A key component of innovation is the development of new products, services, and processes essential to the Nation's international leadership. Just as in generations past, there are talented students from every demographic and from every part of our Country who with hard work and with the proper opportunities will form the next generation of STEM innovators. The vital importance of innovation to the U.S. economy led the Board to embark on a 2-year exploration of this issue.

Our analyses of research and demographic data, as well as our consultation with a wide range of experts, practitioners, policy-makers, and STEM innovators, led us to identify three major areas where focused attention is essential. First, while there are some examples of high-impact educational policies and practices that are effective in enabling tomorrow's potential STEM innovators to thrive, many more are needed. Second, a commitment to equity and diversity, and analyses of demographic trends, lead to the conclusion that new, ambitious efforts to cast a wide net in seeking and inspiring tomorrow's STEM leaders are critical. Finally, it is clear that when the learning environment is infused with high expectations and a commitment to excellence, the potential for future innovators to flourish is great.

To identify and develop the next generation of STEM innovators, the Board makes three *keystone recommendations*. Each recommendation contains several ***policy actions*** for the National Science Foundation (NSF), other Federal entities, and the Nation. Additionally, for each keystone recommendation, the Board proposes a ***research agenda*** for NSF that will ensure the policy actions are supported by the best available research. The keystone recommendations and a summary of the policy actions are listed below. The findings and research agenda can be found in the main body of the report (pp. 15-25).

Keystone Recommendations:

I. *Provide opportunities for excellence.* We cannot assume that our Nation's most talented students will succeed on their own. Instead, we must offer coordinated, proactive, sustained formal and informal interventions to develop their abilities. Students should learn at a pace, depth, and breadth commensurate with their talents and interests and in a fashion that elicits engagement, intellectual curiosity, and creative problem solving—essential skills for future innovation.

To achieve this goal, the Board proposes the following policy actions:

A. Encourage states and/or local education agencies to adopt consistent and appropriate policies on differentiated instruction, curriculum acceleration, and enrichment, and to recognize the achievement levels of students moving or transitioning to different schools.

B. Increase access to and quality of college-level, dual enrollment, and other accelerated coursework, as well as high-quality enrichment programs.

C. Support rigorous, research-based STEM preparation for teachers, particularly general education teachers, who have the most contact with potential STEM innovators at young ages.

D. Provide Federal support to formal and informal programs that have a proven record of accomplishment in stimulating potential STEM innovators.

E. Leverage NSF's *Broader Impacts Criterion* to encourage large-scale, sustained partnerships among higher education institutions, museums, industry, content developers and providers, research laboratories and centers, and elementary, middle, and high schools to deploy the Nation's science assets in ways that engage tomorrow's STEM innovators.

F. Create NSF programs that offer portable, merit-based scholarships for talented middle and high school students to participate in challenging enrichment activities.

G. Increase the technological capabilities and network infrastructure in rural and low-income areas, and expand cyber-learning opportunities.

H. Create a national database of formal and informal education opportunities for highly talented students, and publicize and promote such opportunities nationally to parents, education professionals, and content and resource providers.

II. ***Cast a wide net*** to identify *all* types of talents and to nurture potential in *all* demographics of students. To this end, we must develop and implement appropriate talent assessments at multiple grade levels and prepare educators to recognize potential, particularly among those individuals who have not been given adequate opportunities to transform their potential into academic achievement.

To achieve this goal, the Board proposes the following policy actions:

A. Improve pervasiveness and vertical coherence of existing talent assessment systems.

B. Expand existing talent assessment tests and identification strategies to the three primary abilities (quantitative/mathematical, verbal, and spatial) so that spatial talent is not neglected.

C. Increase access to appropriate above-level tests and student identification mechanisms, especially in economically disadvantaged urban and rural areas.

D. Encourage pre-service education and professional development for education professionals (including teachers, principals, and counselors) in the area of talent identification and development.

E. Encourage pediatricians and early childhood educators, especially *Head Start* teachers, to become knowledgeable about early signs of talent and the need for its nurturance.

III. ***Foster a supportive ecosystem*** that nurtures and celebrates excellence and innovative thinking. Parents/guardians, education professionals, peers, and students themselves must work together to create a culture that expects excellence, encourages creativity, and rewards the successes of all students regardless of their race/ethnicity, gender, socioeconomic status, or geographical locale.

To achieve this goal, the Board proposes the following policy actions:

A. Create a national campaign aimed at increasing the appreciation of academic excellence and transforming stereotypes towards potential STEM innovators.

B. Encourage the creation of positive school environments that foster excellence by providing professional development opportunities for teachers, principals, counselors, and other key school staff.

C. Support the expansion of computing and communications infrastructure in elementary, middle, and high schools to foster peer-to-peer connections and collaborations, and direct connections with the scientific research community.

D. Hold schools, and perhaps districts and states, accountable for the performance of the very top students at each grade.

E. Have NSF, in partnership with the Institute of Education Sciences, hold a high-level conference to bring together researchers in the learning sciences, other scientists, education school administrators, current teachers and principals, and teacher professional associations to discuss teacher preparation and pedagogical best practices aimed at fostering innovative thinking in children and in young adults.

The United States is faced with a clear and profound choice between action and complacency. The Board firmly believes that a coherent, proactive, and sustained effort to identify and develop our Nation's STEM innovators will help drive future economic prosperity and improve the quality of life for all. Likewise, providing opportunities for all young men and women to reach their potential will serve the dual American ideals of equity *and* excellence in education. The decisive action taken years ago in the wake of Sputnik created a legacy guaranteeing that today's generation would live in a more prosperous and secure society than that of their predecessors. It is our collective responsibility today to do the same, and ensure that future generations reap the benefits of our choice to act. We believe that the recommendations set forth in this report represent one step of many towards continuing this legacy.

INTRODUCTION

In 1957, under the shadow cast by the Soviet Union's successful launch of Sputnik, the United States embarked on a coordinated, decade-long effort to recruit and educate the "best and brightest" who subsequently would form a new generation of leaders and innovators in science and engineering (S&E). This endeavor ushered in a new era of unprecedented scientific and technological advancement in the Nation, leading to the creation of new industries and job opportunities, improvements in national security, and enhancements in our quality of life. At the root of this progress was a nationwide focus on excellence in science, technology, engineering, and mathematics (STEM) education and talent development, along with a substantial investment in research and development (R&D). By the 1970s, however, this national sense of urgency and commitment to excellence in STEM education had lapsed into complacency. In 1983, the landmark report, *A Nation at Risk*, noted that "the ideal of academic excellence as the primary goal of schooling seems to be fading across the board in American education."[3] In 2005, nearly a quarter century after *A Nation at Risk*, the alarm once again was sounded over the looming challenge to U.S. pre-eminence in science and technology (S&T) in the National Academies' seminal report, *Rising Above the Gathering Storm*.[4] This report posited that in the 21st century, educated, talented, motivated people and their ideas are paramount to creating the innovations that will sustain America's prosperity.[5] Finally, in 2009, the Administration's *Strategy for American Innovation* argued for investing in the building blocks of innovation, promoting competitive markets, and catalyzing breakthroughs for our Nation's priorities.

A critical facet of America's historical advantage in S&T innovation has been the ability to attract, develop, and retain talented individuals from abroad. Indeed, over the past few decades, many STEM fields in the United States have become increasingly dependent on foreign-born talent. However, global competition for STEM talent is growing as many countries increase their R&D capacity and improve their own STEM education systems. In light of this, it remains essential that the Nation not only continue to attract STEM talent from abroad, but also renew and redouble its efforts to identify and develop domestic human capital as well.

The Board's 2-year examination of this issue made clear one fundamental reality: ***the U.S. education system too frequently fails to identify and develop our most talented and motivated students who will become the next generation of innovators.*** Whether this group of students has access to appropriate resources seems to be an accident of birth—whether they are a part of a supportive and knowledgeable family or are residing in a community that has programs and opportunities available to them. There are students in every demographic and in every school district in the United States with enormous potential to become our future STEM leaders and to define the leading edge of scientific discovery and technological innovation. Some of our Nation's most talented students—perhaps through sheer individual will, good fortune, and circumstance—rise through the educational system and become leading contributors to the scientific workforce. Regrettably, far too many of our most able students are neither discovered nor developed, particularly those who have not had adequate access to educational resources, have not been inspired to pursue STEM, or who have

The possibility of reaching one's potential should not be met with ambivalence, left to chance, or limited to those with financial means. Rather, the opportunity for excellence is a fundamental American value and should be afforded to all.

faced numerous other barriers to achievement. The possibility of reaching one's potential should not be met with ambivalence, left to chance, or limited to those with financial means. Rather, the opportunity for excellence is a fundamental American value and should be afforded to all.

Although many past and current educational reforms have focused on the vital goal of raising the general performance of all students, far fewer have focused on raising the ceiling of achievement for our Nation's most talented and motivated students. The Board asserts that educational opportunity is not a zero-sum game: *true equity* means we must address the needs of *all* students. Mutually reinforcing results can be realized when we improve general educational performance as well as identify and stimulate potential leaders in STEM whose creativity and ideas can benefit all. The critical goal of increasing STEM proficiency and general scientific literacy does not compete with, but rather complements, today's renewed clarion call for excellence. The needed focus on excellent STEM instruction that will inspire and excite those who might pursue STEM careers is crucial for *all* learners.

Today, on the 60th anniversary of the National Science Foundation, the United States is confronted with a clear choice between action and complacency. The Board firmly believes that a coherent, proactive, sustained effort to identify and develop our Nation's future STEM innovators will help drive future economic prosperity, improve the quality of life for all, and ensure both equity *and* excellence in education.

STEM "innovators" are defined in this report as those individuals who have developed the expertise to become leading STEM professionals and perhaps the creators of significant breakthroughs or advances in scientific and technological understanding. Historical examples include Edison, Ford, Fleming, Pasteur, Einstein, and Curie. This report alternately refers to the children and young adults who have the most potential to become STEM innovators as "talented and motivated" or "high-ability" or "gifted."[6] Their capabilities often include mathematical and spatial abilities[7] alone or in combination with verbal aptitude, along with other factors such as creativity, leadership, self-motivation, and a diligent work ethic. In an increasingly technological society, innovation is frequently an interdisciplinary endeavor and many traditional non-STEM fields require scientific, spatial, and quantitative talents.

RATIONALE

Two sets of fundamental national values and needs underlie the findings and recommendations proffered in this report. The first set relates to the national need for the entire Country to reap the full rewards of science and technology and their application. America has benefited tremendously over the past 60 years from its investments in developing the world's top scientific enterprise. Increased efforts in a variety of areas, including development of our human capital, will be required to maintain America's international position in S&T as other countries have recognized this accomplishment and seek to emulate it. The second set relates to the American value reflected in providing equal opportunities for all students to reach their full potential and thrive in modern society. Serving the needs of all students, including high-ability students, will help achieve our Country's aspiration for true equality of educational opportunity and will facilitate the development of the innovators of tomorrow who can lead the way forward. Our combined actions today towards meeting these two values and needs will serve as our legacy to the next generation.

Developing Future STEM Innovators: An Economic Imperative

The identification and development of our Nation's human capital are vital to creating new jobs, improving our quality of life, and maintaining our position as a global leader in S&T. In 1945, in the immediate aftermath of World War II, and long before "innovation" became commonplace in our collective vernacular, the necessity of progress in STEM fields was emerging. In *Science–The Endless Frontier*, Vannevar Bush wrote:

> *Our hope is that there will be full employment, and that the production of goods and services will serve to raise our standard of living...Surely we will not get there by standing still...There must be a stream of new scientific knowledge to turn the wheels of private and public enterprise.*[8]

Since then, and with increasing frequency over the past decade, a variety of prominent government and private organizations have warned against "standing still" and forcefully articulated the importance of innovation and talent development to the U.S. economy. Indeed, the innovations that spawn high-technology industries will create new employment opportunities at a rate that exceeds traditional manufacturing industries.[9] A full 65 years since the publication of *Science–The Endless Frontier*, and as the world recovers from a global economic downturn, the unmistakable link between the prescient words of Vannevar Bush in 1945 and those of the Administration in 2010 engenders a renewed poignancy:

> *In our increasingly interconnected and globally competitive world economy, unleashing innovation is an essential component of a comprehensive economic strategy. As global competition erodes the return to traditional practices, the key to developing more jobs and more prosperity will be to create and deploy new products and processes.*[10]

Innovation is the complex process of introducing novel ideas into use or practice in order to develop cutting-edge breakthroughs in emergent fields (e.g., energy sustainability, personalized medicine) as well as novel solutions to age-old problems (e.g., the need for clean and abundant water). Innovation requires highly able, determined, and creative leaders and thinkers. We are now living in what the Council on Competitiveness calls the "conceptual economy," where competitive advantage and value creation rely on "insight, imagination, and ingenuity."[11] So, where will we find our future STEM innovators? Longitudinal data show that intellectually talented individuals who can be identified at an early age (and then supported in their learning) generate a disproportionate number of Fortune 500 patents, peer-reviewed STEM publications, and other creative achievements, and comprise a disproportionate number of tenured academic faculty at top universities.[12] Clearly then, a critical challenge in this "conceptual economy" is to discover and then develop the next generation of innovators who will help create the "products and processes" that will fuel our future economic prosperity.

Is the United States meeting this challenge in a world where international competition is accelerating? Although the United States remains among the leaders in key metrics of innovation and R&D investment, there may be cause for concern. Distressingly, students in other countries are outperforming even our highest-achieving students. In the 2006 Program for International Student Assessment (PISA) test, U.S. 15-year-olds in the 90th percentile (our top students) scored below their peers in 29 countries on mathematics literacy, and below 12 countries on science literacy.[13] Similarly, 6 percent of America's eighth graders reached the advanced benchmark in mathematics on the 2007 Trends in International Mathematics and Science Study (TIMSS).[14] Though this marks an above average score, the performance of U.S. students fell well behind several key competitors. For example, 40 percent of eighth graders from the Republic of Korea and Singapore, and 45 percent of eighth graders from Chinese Taipei (Taiwan) reached the advanced benchmark in mathematics.[15]

Some worrisome indicators are also present beyond K-12 within the higher education system and STEM workforce. There has been an ongoing debate among experts whether there are indeed deficiencies in the U.S. STEM pipeline that inevitably will lead to a future workforce shortage in at least some S&E fields. Critically, even if the overall supply of U.S. citizens entering the STEM pipeline is equal to the demand (or even exceeds demand in some fields), there is evidence that top U.S. students, who have a disproportionate potential to become future innovators, are eschewing careers in S&E. A 2002 analysis showed that between 1992 and 2000, the number of the highest-achieving students intending to enter graduate study in an S&E field declined 8 percent overall, with particularly steep declines in engineering (25 percent) and mathematics (19 percent).[16] Similarly, a more recent report provided evidence that, between the 1990s and mid-2000s, there was a sharp decline in the number of highest-achieving U.S. high school graduates enrolling in or completing a STEM major in college.[17] While the percentage of top U.S. students entering many S&E fields has declined in recent years, many of these same fields have become increasingly reliant on foreign-born talent.[18] For example:

- Compared to their U.S. counterparts, undergraduate students in foreign countries chose natural science and engineering (NS&E) disciplines as their primary field of study at considerably higher rates. According to the most recent data, 25 percent of undergraduates in the European Union, 47 percent in China, and 38 percent in South Korea chose an NS&E major, compared to only 16 percent of U.S. undergraduates.[19]

- This trend continues further along the STEM pipeline: 33 percent of all U.S. STEM doctoral students in U.S. universities are foreign students on temporary visas, and 57 percent of U.S. postdoctoral fellows in STEM fields hold temporary visas.[20]

- Foreign-born doctoral degree holders constitute an increasing share of the S&E workforce. In 2003, foreign-born doctorate holders represented about half of the workforce in engineering and computer science, and 37 percent and 43 percent of the workers in the physical sciences and mathematics, respectively.[21]

Attracting and retaining foreign-born talent remains an essential pillar of our Nation's STEM enterprise. As global demand for STEM talent surges, we cannot reliably expect that the best and brightest from abroad will remain in the United States and continue to be a sufficient source of talent. It is essential that we develop our own domestic human capital as well. Ideally, foreign talent should augment a robust domestic STEM talent pipeline, not compensate for its deficiencies.

Our Nation's success in developing future STEM innovators rests squarely on the capacity of our education system to identify and nurture ability. This ability can manifest itself in a variety of ways, across many different developmental stages. In the United States, assessments of verbal and mathematical aptitude are well-established and widely used. Yet, a talent highly valuable for developing STEM excellence—spatial ability—is not measured and hence missed. Recent research indicates that current mathematics and verbal talent assessments would miss 70 percent of students scoring in the top 1 percent of spatial ability.[22] Individuals with such talents constitute a lost resource for creating future STEM innovation, since 90 percent of STEM doctorate holders scored in the top quartile of spatial ability during adolescence.[23] As discussed in the next section, another unrealized resource is young men and women from lower-income backgrounds and minorities traditionally underrepresented in STEM. Underrepresented minorities are disproportionately absent from the current STEM workforce but comprise the fastest growing college-aged population in the United States.[24] Similarly, though our Country has made laudable strides in narrowing the gender gap in STEM participation, women are still underrepresented in fields such as engineering, computer science, and the physical sciences.[25]

While the need for future STEM leaders and visionaries is great, our Nation sits atop an untapped talent gold mine. We are faced, therefore, with a clear and profound choice between action and complacency. We believe the choice is as simple as it is vital: Securing our Nation's continued economic prosperity will require the proactive identification and development of talented young men and women from *all* demographics with *all* types of STEM-related abilities who have the potential to become our next generation of STEM innovators.

In light of the economic importance of scientific and technological innovation, increasing global competition, and our dependence on foreign-born talent, we must reawaken a national expectation of excellence. The 2005 Business Roundtable report, *Tapping America's Potential: The Education for Innovation Initiative*, effectively enunciates this point:

> *One of the pillars of American economic prosperity—our scientific and technological superiority—is beginning to atrophy even as other nations are developing their own human capital. If we wait for a dramatic event—a 21st-century version of Sputnik—it will be too late. There may be no attack, no moment of epiphany, no catastrophe that will suddenly demonstrate the threat. Rather, there will be a slow withering, a gradual decline, a widening gap between a complacent America and countries with the drive, commitment and vision to take our place.*[26]

Our continued economic prosperity will depend on a skilled workforce, particularly at the leading edge of science and technology, where a diverse legion of creative, motivated and innovative individuals is essential. Changing course is a long-term proposition. It requires significant foresight and early intervention. Although mastery of a STEM discipline requires over a decade of intensive study after high school, the interest (or disinterest) in STEM germinates early in K-12, maybe even in early childhood. Likewise, no matter how talented the individual, realization of this potential may not occur on its own. Development of our Country's human capital requires the identification and development of all types of STEM-related talents, the encouragement of intellectual ambition, an anticipation of excellence rather than simply competency, and the sustained nurturing of the creative spark. America can create, through its educational system, the next generation of preeminent scientists, engineers, inventors, and entrepreneurs when it focuses its collective will on that critical goal. As a society, we will reap the benefits for decades to come.

Opportunity for Excellence: A Fundamental Value

Equality in educational opportunity means that *all* students fundamentally deserve the chance to succeed in reaching their highest potential. When disparities in academic achievement exist among populations, we have marshaled our collective will in an effort to narrow these gaps. As a result of these efforts, the U.S. education system has experienced some notable improvements. Nonetheless, too many students in America are not achieving even at modest levels, and great disparities continue to exist in the quality of education afforded to students around the Nation. Efforts to raise the educational achievement for all students must not only be continued in earnest, but accelerated. However, to reach *true* equality of opportunity, and to ensure that potential does not go unrealized, we must not overlook the educational needs of our Nation's most talented and motivated students. Too often, U.S. students with tremendous potential to become our future innovators go unrecognized and undeveloped. The dual goals of raising the floor of base-level performance and elevating the ceiling for achievement are not mutually exclusive. The Board believes that both equity *and* excellence are not only possible and mutually reinforcing, but necessary to achieve the American ideal as eloquently articulated 65 years ago in *Science–The Endless Frontier*:

> *We think it is much the best plan, in this constitutional Republic, that opportunity be held out to all kinds and conditions of men [and women] whereby they can better themselves. This is the American way, this is the way the United States has become what it is. We think it is very important that circumstances be such that there be no ceilings, other than ability itself, to intellectual ambition. We think it very important that...if he [and she] has what it takes, the sky is the limit.*[27]

Unfortunately, individuals with a high level of ability and determination frequently lack the opportunities needed to reach their potential. There are examples of successful programs and interventions aimed at advanced learners. Many of today's top scientists, inventors, and entrepreneurs participated in one or more of these programs at some point in their academic development.[28] Indeed, data show that a high density of advanced pre-collegiate learning opportunities among mathematically talented youth has been linked to subsequent accomplishments in STEM.[29] Yet the scale of these programs is often small, and access to these programs is frequently limited. More often than not, across the education ecosystem, we see a patchwork of individual, often *ad hoc* provisions implemented and funded at the local level; these approaches have been instrumental for many of today's STEM innovators and should continue. In addition, a coherent, long-term, state- or Nation-wide plan to develop the next generation of leaders in STEM is also needed. Our Nation has too often left to chance the fate of those with exceptional talent rather than ensuring widespread, systematic, and appropriate opportunities to flourish.

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Historically and by law, states and local education agencies (LEAs) are the primary source of support for talented learners and often represent the only source of support. Not surprisingly then, the funding and education policies among the states and even districts within the same state vary considerably. The National Association for Gifted Children's (NAGC) *State of the States in Gifted Education* report describes the situation for gifted and talented education at the state and local levels.[30] In 2008-2009, out of the 45 states that fully responded to the NAGC survey:

- 32 states required school districts to provide some services for gifted and talented students. Of these 32 states, only 6 reported fully funding these services.
- 12 states provided no funds to support gifted education.
- Among the 14 states that reported both funding levels and numbers of identified gifted students, the yearly allocation per child ranged from less than 2 dollars to approximately 760 dollars.
- 11 states required districts to accept gifted identification decisions from other districts in the same state.
- Most high-ability children were placed in the general classroom where the majority of teachers have little or no specialized training in working with gifted children.
- Only five states required *all* teachers to have pre-service training in gifted and talented education. Only five states required annual professional development for teachers in specialized gifted and talented programs.
- 21 states reported that they neither monitor nor audit local programs for talented students.

Meanwhile, support from the Federal Government at the elementary, middle, and high school levels for our high-ability youth is minimal. A single program at the Department of Education, the *Jacob K. Javits Gifted and Talented Students Education Program*, is specifically dedicated to supporting talented students. Even this program is routinely targeted for elimination due to Federal budgetary considerations.[31] The National Science Foundation (NSF) has a few general STEM education programs that could potentially support research in this area, such as *Discovery Research K-12* and *Research and Evaluation on Education in Science and Engineering*. However, NSF currently does not have any programs or initiatives specifically dedicated to the direct support of, or research into, our Nation's future innovators at the K-12 level.[32] In the absence of a coordinated plan and consistent opportunities for young men and women across the entire Country, talented students may slip through the cracks or face bureaucratic, institutional, societal, and/or other hurdles that stymie their progress and suppress intellectual ambition.[33]

Findings from the 2007 *Achievement Trap* report suggest that educators, policy-makers and even parents erroneously assume that high-achieving young men and women will continue to achieve at high levels on their own and do not need additional support.[34] However, an analysis of the performance of high-achieving students on the National Assessment of Educational Progress (NAEP) paints a different picture. Whereas the scores of students in the tenth percentile (low achievers) have seen significant improvements over the past decade, test scores for students in the ninetieth percentile (high achievers) have, at best, experienced modest gains and, at worst, stagnated.[35] The situation for highly talented and motivated students from lower socioeconomic backgrounds and underrepresented minorities is especially alarming. Although high achievers can be found in every geographic area and every race/ethnicity,[36] data from *Achievement Trap* show that talented students from lower-income levels are underrepresented and lose ground at virtually every stage along the educational continuum.[37] For example:

- Approximately 3.4 million children rank in the top quartile academically and come from households with incomes below the national median. At every educational level they fare worse in terms of academic outcomes compared to their higher-income counterparts. Thus, these students represent a potentially significant source of underdeveloped talent.

- Disparities begin early: In first grade, 72 percent of students in the top quarter of their class come from higher-income families, compared to only 28 percent of lower-income students. According to the authors of *Achievement Trap*, this disparity means, "200,000 or more children from lower-income backgrounds appear to be lost each year from the ranks of high achievers before their formal education ever begins."[38]

- Lower-income students *fall out of* the top quartile during elementary and high school at significantly higher rates than their higher-income peers.

- Lower-income students are considerably less likely than higher-income students to *rise into* the top quartile during elementary and high school, attend the most selective colleges, finish a baccalaureate degree, or go on to complete a graduate degree.

Likewise, achievement gaps between white or Asian/Pacific Islander students and minorities traditionally underrepresented in STEM exist at *all* levels, including significant gaps among the highest-performing students. For example, a recent analysis of both NAEP and state assessment data shows that large achievement gaps in mathematics performance continue to persist between white and underrepresented minority high achievers.[39] Moreover, extremely low percentages of minority students reach the advanced level on NAEP. In 2007, only 0.8 percent of African American students and 1.5 percent of Hispanic students reached the advanced level on the fourth grade NAEP mathematics exam. Similarly, only 0.9 percent of African American students and 1.8 percent of Hispanic students reached the advanced level on the eighth grade NAEP mathematics exam. In comparison, 7.6 percent and 9.4 percent of white students reached the advanced level in mathematics in fourth and eighth grade, respectively.[40] These and other data underscore a systematic lack of opportunities and support for underrepresented minority students, inadequate teaching, and an absence of both real-life, hands-on experiences with STEM materials and positive role models of STEM professionals.[41]

Talented underrepresented minorities also face significant inequities that contribute to the achievement gap at the high end of academic performance. For instance, African American, Hispanic and American Indian/Native Alaskan students are underrepresented in gifted and talented programs in K-12, attain lower SAT scores, are less likely to take advanced mathematics courses or Advanced Placement (AP) exams, attend less prestigious higher education institutions, and are less likely to graduate with a degree compared to whites and Asians/Pacific Islanders.[42] Consequently, many of our most talented and determined lower-income students and minority students traditionally underrepresented in STEM are never identified or given an equal opportunity to realize their enormous potential, and, therefore, constitute a considerable source of untapped talent.

"If you win the NCAA championship, you come to the White House. Well, if you're a young person and you've produced the best experiment or design, the best hardware or software, you ought to be recognized for that achievement, too. Scientists and engineers ought to stand side by side with athletes and entertainers as role models."

Barack Obama,
U.S. President
November 23, 2009[43]

The attitudes of educators, policy-makers, parents, students' peers, and even students themselves toward excellence can act as facilitators of, or form considerable barriers to, academic achievement. Our society almost universally applauds certain areas of talent—sports in particular, and to a lesser extent music and the arts. In contrast, intellectual talent often generates attitudes ranging from ambivalence to outright hostility.[44] A 2008 survey revealed that 86 percent of teachers said that to attain the American ideals of justice and equality, it was important to focus equally on all students, regardless of their backgrounds or achievement levels. Nevertheless, only 23 percent of teachers indicated that academically advanced students were a priority at their school. Similarly, 73 percent of teachers surveyed agreed that "too often, the brightest students are bored and under-challenged in school" and are not given sufficient opportunities to thrive.[45] Moreover, the vast majority of general education teachers receive little or no training on pedagogical best practices for talented learners.[46] Consequently, most teachers make only minor and irregular modifications to the regular classroom curriculum to serve the academic needs of these students.[47] With the proper attention from teachers and administrators, these students could access a component of the learning support infrastructure vital to achievement.

An unsupportive or negative learning ecosystem can undermine self-efficacy—that is, beliefs about one's capabilities to learn or perform at designated levels. Women, for example, are underrepresented in the engineering profession, and female engineering undergraduates experience high attrition rates.[48] Low self-efficacy of aspiring female engineers correlates with a perceived lack of inclusion in engineering classrooms, possibly due to negative attitudes of peers and faculty, and could be partly to blame for this phenomenon.[49] Some evidence exists that the low participation of underrepresented minorities in gifted education programs is caused in part by the diminished expectations of educators, due to negative and stereotypic views regarding the academic ability of these students.[50] The resulting lack of diversity then may lead underrepresented minority students who *do* participate in gifted programs to feel isolated and not part of the classroom experience. As a result, they may withdraw from classroom activities and hide their abilities from teachers and peers.[51]

Similarly, misconceptions regarding intelligence may form additional barriers to achievement. Some research indicates that, to a certain extent, ability and intelligence are malleable—that is, rather than being a fixed trait, some abilities potentially can be developed over time with hard work and the proper support. Nevertheless, many students and teachers believe that intelligence is a fixed trait, and this belief can hinder a student's motivation and ability to learn and improve. This mindset can have particularly pernicious effects on the learning and achievement of women and underrepresented minorities.[52] Critically, the belief in fixed intelligence can create a fear of failure within a student, yet innovation requires risk taking and outside-of-the-box thinking. Even studies of geniuses and landmark creative accomplishments demonstrate that talent alone is insufficient, and sustained, diligent training and practice are indispensable.[53]

Further compounding the issue, talented students from many demographics may face a social stigma that too often accompanies academic success. In particular, African American and Hispanic students in public schools sometimes experience anti-intellectual social pressure from peers, which negatively impacts performance.[54] High-ability Hispanic students also may face linguistic barriers that hinder academic achievement, and tend to have lower academic aspirations compared to higher-income, white students even when they possess the requisite ability and training.[55] Because women and underrepresented minorities are disproportionately absent from many STEM disciplines, and Hispanics in particular are the largest growing college-aged population,[56] identifying and supporting these students are vital to both the concept of equity and ensuring a robust, diverse workforce for the future. Creating a society and culture whose institutions, especially schools, value and reward academic excellence represents a national responsibility.

RECOMMENDATIONS

The innovation continuum, from identification and development of talented and creative individuals through the education system, to a STEM career, and then to major scientific breakthroughs or to the creation of a novel product, is both vast and complex. Even with unlimited time and resources, the Board would be hard-pressed to address every facet of the innovation process. Therefore, we have chosen to focus on the human capital component, especially early in the education system, where we feel much of our domestic talent goes unrecognized and undeveloped. Thus, the following recommendations are not exhaustive and not intended to be the final word on the subject.

Though we are focused on identifying and developing future innovators in STEM, several of our recommendations could benefit *all* students.[57] This is by design. Similarly, many findings and techniques found effective for the general population of students may prove useful for high-ability students. The Board recognizes that excellence is an objective that *all* U.S. students should endeavor to attain. Other recommendations we propose clearly reflect our finding that talented students have some learning needs that are distinct from those of the general population. **Ultimately, our hope is that the needs of our future STEM innovators increasingly will become part of the national education discourse among the public and policy-makers alike. We encourage others to join our call for a renewed commitment to both equity *and* excellence for all students, so that potential is never squandered, intellectual ambition need not hide, and creative ability blossoms.**

In this section, we outline three broad ***keystone recommendations*** based on the findings from the expert panel discussion hosted by the Board in August 2009 (see Appendix III) and the Board's 2-year study of this issue. Contained within each keystone recommendation are multiple specific ***policy actions*** for NSF, the Federal Government, and/or the Nation. Following the policy actions, we propose a ***research agenda*** for each keystone recommendation. Though a substantial body of research and considerable discussion with experts informs our policy recommendations, much remains unknown. NSF, through its broad investments in STEM education, the learning sciences, workforce development, and STEM research, is well positioned to facilitate both a nuanced examination of human capital development and a high-level survey of the entire innovation ecosystem. These research findings will inform policy-making in critical areas, such as identifying future innovators and improving teaching effectiveness, to maximize long-term returns on our investment.

I: Provide Opportunities for Excellence

Improve the access to and availability of effective K-12 formal and informal education programs and interventions to meet the needs of future STEM innovators.

Findings

Inconsistent efforts and resources have been expended to support our Nation's most talented and determined students. As a result, their educational needs often go unmet. Experience shows that without a widespread, equitable, and coherent support system, a full realization of potential is unlikely. Policy-makers have made notable efforts over the past decade to implement standards and accountability in the U.S. education system (e.g., *No Child Left Behind Act of 2001* (NCLB)). Unfortunately, these standards have not mandated increases in—or even the measurement of—advanced levels of educational performance. Regardless of the rigor of standards, schools have become focused on getting children across the basic proficiency threshold.[58] Currently, there are no "standards of excellence" to which schools are held.

There are many individual successful programs available for talented and motivated students interested in STEM.[59] However, many of the existing opportunities are limited in scope and access, or suffer from a lack of resources. In America, it should be possible, even essential, to elevate the achievement of low-performing at-risk groups while simultaneously lifting the ceiling of achievement for our future innovators. Consistent, coherent, and coordinated opportunities that challenge and inspire high-potential students both in and out of the classroom are needed. The Board believes the following findings inform and support the policy actions and research agenda proposed below.

In America, it should be possible, even essential, to elevate the achievement of low-performing at-risk groups while simultaneously lifting the ceiling of achievement for our future innovators.

- Talented, motivated students tend to master curriculum content at a rapid rate and often have mastered 40 to 50 percent of grade-level content before entering each grade.[60] This hunger for new information and further learning can quickly atrophy into boredom if not satisfied.[61] Increased classroom "time on task" is an idea that is gaining popularity among policy-makers, but time on task is squandered if it is spent on a subject that a student has already mastered. Therefore, these students require classroom content and pacing suitable to their individual learning styles, interests, and abilities.[62]

- Research shows that curriculum acceleration, or accelerative learning, is one of the most effective interventions for high-ability individuals.[63] Acceleration is an intervention that moves students through a standard school curriculum faster, or at younger ages, than typical without necessarily requiring the development of specialized curricula. The level and pace of a curriculum is synchronized to the intellectual readiness, emotional maturity, and motivation of the student. Research shows that, by-and-large, those students permitted to accelerate not only achieve more but also are happier than those who are not.[64]

- Accelerative learning generally costs very little, but requires school administrative flexibility, particularly for younger students who are more likely to be denied this opportunity by states and LEAs.[65] Similarly, due to bureaucratic hurdles and/or state and local policies, the ability and prior achievement level of students moving or transitioning (e.g., moving from elementary to middle school) to different schools are sometimes ignored, forcing these students to retake coursework they already have mastered.

- In the STEM areas, all students, including the most talented, should have the opportunity to experience inquiry-based learning, peer collaboration, open-ended, real-world problem solving, hands-on training, and interactions with practicing scientists, engineers and other experts.[66] Currently, many of the opportunities for these activities materialize in the form of informal, out-of-school enrichment activities (e.g., summer camps, competitions, science museum visits, Math Circles), rather than as an integrated ingredient of a STEM curriculum. Out-of-school enrichment is extremely valuable, particularly to inspire interest in STEM, but insufficient by itself. Students spend the vast majority of their time in the regular, formal classroom.[67] Formal and informal education are mutually reinforcing and are most effective when synchronized.[68]

- Formal and informal enrichment programs are limited in their prevalence and persistence, particularly for students in poorly funded locales.[69] When combined with acceleration, enrichment is especially powerful and should be included.[70] Emerging technologies can be instrumental in providing schools access to meaningfully enriching STEM resources. Through the Internet students can connect to formal and informal learning opportunities and STEM experts, gain interactive access to world-renowned museum collections and a vast array of digital STEM content, and participate in virtual laboratories.

- Early exposure to STEM is particularly important, since interest in STEM often begins to blossom in elementary school, and early exposure to science can strongly influence future career plans.[71]

- Engineering is a field critical to innovation, and exposure to engineering activities (e.g., robotics and invention competitions) can spark further interest in STEM. However, exposure to engineering at the pre-collegiate level is exceedingly rare.

- Some students who show potential for high achievement are not prepared for advanced content because they have not had access to appropriate resources or have not been challenged by their learning environment. One way to address this issue is through special "bridge" programming. Bridge programs can help elevate student achievement to a level commensurate with individual potential, improve confidence, and enable students to engage in classroom activities at the level of their high-achieving peers so they can fully benefit from the experience.[72]

Policy Actions

A. Encourage states and/or local education agencies to adopt consistent and appropriate policies on differentiated instruction, curriculum acceleration, and enrichment, and to recognize the achievement levels of students moving or transitioning to different schools. States and LEAs should examine ways to remove bureaucratic or policy-related barriers and increase administrative flexibility so as to allow students—beginning in early grades—to proceed at a pace that matches their individual ability and interest.[73]

B. Increase access to and quality of college-level, dual enrollment, and other accelerated coursework (e.g., Advanced Placement and International Baccalaureate classes), as well as high-quality enrichment programs. Particular attention should be given to increasing the participation and success of underrepresented and low-income groups in these classes.

C. Support rigorous, research-based STEM preparation for teachers, particularly general education teachers, who have the most contact with potential STEM innovators at young ages. Attention should be given to training teachers in the most effective methods of teaching STEM content, including hands-on and unstructured problem solving and inquiry-based learning.

D. Provide Federal support to formal and informal programs that have a proven record of accomplishment in stimulating potential STEM innovators. These should include formal education programs that use innovative teaching methods or employ inquiry-based learning, and informal programs, such as robotics and invention competitions, Math Circles, hands-on "lab days", mentoring opportunities, and science fairs. Attention also should be given to programs that satisfy one or more of the following:

- Provide "bridge" experiences for students with high potential who have not had consistent past opportunities for achievement;
- Have proven effective in promoting diversity, or reducing the achievement gaps at the "high end" of academic performance based on race/ethnicity, gender, and/or income level;
- Have demonstrated success in lowering the attrition rate at the high school to higher education transition point.

E. Leverage NSF's *Broader Impacts Criterion* to encourage large-scale, sustained partnerships among higher education institutions, museums, industry, content developers and providers, research laboratories and centers, and elementary, middle, and high schools to deploy the Nation's science assets in ways that engage tomorrow's STEM innovators. Particular attention should be given to mentoring opportunities for students in K-12 and partnerships that engage students and teachers in K-12 in entrepreneurial, innovative environments.

F. Create NSF programs that offer portable, merit-based scholarships for talented middle and high school students to participate in challenging enrichment activities, such as summer programs, Math Circles, hands-on research experiences, and competitions. The scholarship criteria should emphasize identifying students who possess high potential but who have not had consistent prior opportunities to demonstrate academic excellence.

G. Increase the technological capabilities and network infrastructure in rural and low-income areas, and expand cyber-learning opportunities. Some examples of these opportunities include access to digital resources, remote connections with STEM experts, the creation of online learning communities, and virtual laboratories.

H. Create a national database of formal and informal education opportunities for highly talented students, and publicize and promote such opportunities nationally to parents, education professionals, and content and resource providers.

Research Agenda

Rigorous evaluation data regarding existing educational services and their outcomes are frequently lacking. Therefore, a key component of a research agenda must be a candid analysis of which educational and enrichment interventions work (and how well, for whom, and under what conditions) and which do not, in the short-run and long-term. In a climate where education resources are scarce, it is essential to provide policy-makers with empirical evaluation data to aid their funding decisions. Moreover, evaluation data are equally important for educators and parents who bear the primary responsibility for ensuring that talented children and young adults are given worthwhile opportunities to cultivate their abilities. Some outcome evaluations are available, but few are effective in providing the education community with the generalizable knowledge needed to build better interventions. Although programmatic knowledge—that is, specific information applicable *only* to a particular intervention—is an important component of evaluation, there is a need for generalizable knowledge, which can be used across programs and perhaps even across disciplines. We recommend the following four priorities for the research agenda:

1. Examine NSF's current *Broader Impacts Criterion* relative to STEM education for highly talented and motivated K-12 students. Serving highly talented and motivated individuals in K-12 and beyond should be a means for satisfying this criterion. Higher education institutions are well suited for this role and should be encouraged to do so.

2. Provide support for independent external evaluations on the short- and long-term outcomes of Federal, state, and local programs focused on high-ability individuals or groups. Evaluations should be designed such that data generated are generalizable to a broad array of programs, thus increasing the knowledge base of best practices. Emphasis should be given to studying the impact of these programs on the three criteria listed under "Policy Action D" above.

3. Investigate the scalability and replicability of successful programs and best practices.

4. Support research on designing novel, innovative methods for developing talents. In addition, researchers should explore effective means for implementing these techniques in education schools, and teacher preparation and professional development programs.

II: Cast a Wide Net

Improve the identification of potential STEM innovators—especially among underrepresented populations—by augmenting teacher training and using talent assessments that 1) span the entire K-12 continuum, 2) reflect the multiple domains of ability (e.g., verbal, mathematical, spatial), 3) have sufficient range at the top to distinguish high from extremely high ability, and 4) are appropriately matched to the background, education history, and prior achievement history of the individual.

Findings

The abilities of large numbers of potential future STEM innovators currently go unrecognized and are underdeveloped. Though cognitive ability is only one of many attributes of a future innovator, it is important. Identifying this ability as early as possible is critical for developing an appropriate educational intervention. Abilities may develop at different rates for different individuals, so educators must diligently seek out potential throughout the entire educational continuum. Identification of the most talented students, whether their talents are verbal, mathematical, or spatial, is improved by the use of above-level tests—that is, tests designed for older students—as part of the suite of identification activities. When age-appropriate tests are used, both high- and extremely high-ability students are not distinguishable in the test results. Above-level testing provides vital information that allows for a better tailoring of educational experiences. Likewise, educators require the training and experience to recognize talented students and facilitate their entry into the appropriate programs or interventions.

Research shows that high ability is present across all demographics. Yet, underrepresented minorities and students from low-income backgrounds are disproportionately absent from gifted classrooms and drop out of the "high achieving" category during elementary and high school at alarming rates.[74] Increased global competition for talent and shifting racial/ethnic demographics in the United States underscore the importance of casting a wider net to capture all forms of STEM-related talents, in all of the places it can be found. The policy actions and research agenda below are supported by the following findings:

- Talent is not a binary phenomenon (i.e., "you have it or you don't"). Research shows that ability is dynamic, can be developed over time with proper training, and the developmental process can occur at different paces for different people.[75] Assessments must be given early and often throughout K-12 rather than a single test administered at a single or just a few developmental stages.

- Identification and development go hand-in-hand. To properly identify and assess students with high potential, interest and talent in STEM should be developed at an early age. Opportunities for educational development in STEM can unmask or improve general or domain-specific cognitive abilities and critical non-cognitive abilities, such as persistence, creativity, and leadership. As these abilities are developed, identification mechanisms improve.

- Verbal and quantitative/mathematical skills are two of the most commonly understood and assessed abilities. Numerous tests for these skills are deployed to identify children whose performance is well beyond that of the typical child. Talent searches are widespread in seventh and eighth grade but less well developed at younger ages.

- Future achievement in STEM is linked to the pattern of abilities present in an individual. For example, mathematical and spatial ability alone or in combination have been associated with STEM expertise and are predictive of a future career in S&E.[76]

- Spatially talented students may not fit the classic model of what parents, the public, and even educators think of as "gifted." Rather than excelling in a typical classroom, these individuals might actively engage in vocational or career training classes or in projects outside of school where they can perform hands-on activities in three dimensions. These students may gravitate to engineering classes if offered early in the curriculum. Individuals with spatial abilities are routinely overlooked because these abilities are rarely measured and, if they are, the results often are not given the proper attention. This is an untapped pool of talent critical for our highly technological society.[77]

- Opportunities for achievement and success have not been afforded equally to all talented individuals or groups. Results from any testing, whether it is on-level or above-level, need to be considered in light of the backgrounds of the students taking the test and their prior opportunities to learn and achieve.[78] A student may not appear exceptional if his or her performance is compared to national norms. However, if individual context, such as being an English language learner, being the first in his or her family to graduate from college or even high school, coming from a low-income background and/or an environment lacking intellectual stimulation is considered, his or her performance may stand out and be indicative of high potential.

- Teachers often act as "gatekeepers" to gifted classrooms and resources.[79] However, they frequently receive inadequate or no training on how to identify and develop students with high potential.[80] The most talented students or students with the highest potential may not always be the "best students" with the highest grades, or the most well behaved students.

Policy Actions

A. Improve pervasiveness and vertical coherence of existing talent assessment systems.

- Rather than administer a single assessment at a single developmental stage or grade level, provide multiple above-level tests throughout the K-12 continuum.
- Encourage schools to improve vertical coherence by tracking the progress of students identified as having high ability beginning in kindergarten all the way through to completion of high school and beyond. It should be a category for which schools are monitored for making progress or *adequate yearly progress* if this concept is continued in Federal laws.

B. Expand existing talent assessment tests and identification strategies to the three primary abilities (quantitative/mathematical, verbal, and spatial) so that spatial talent is not neglected. Talent searches should routinely measure spatial ability.

C. Increase access to appropriate above-level tests and student identification mechanisms, especially in economically disadvantaged urban and rural areas. These tests should use standards that are representative of the local norms and account for the prior learning opportunities of the students assessed.

D. Encourage pre-service education and professional development for education professionals (including teachers, principals, and counselors) in the area of STEM talent identification and development. Education schools and other teacher preparation programs should emphasize teacher preparation in all areas of identification, including spatial ability recognition and the identification of talented underrepresented minorities. Teacher training and professional development must rely on the best available research in these areas and should be aligned with evidence of improvements in student identification and outcomes.

E. Encourage pediatricians and early childhood educators, especially *Head Start* teachers, to become knowledgeable about early signs of talent and the need for its nurturance.

Research Agenda

Much is still unknown about the various forms of ability and their relationship to future innovation. Put simply: How do we best identify individuals who have the potential for future creative and innovative accomplishments in the STEM fields? Clearly, cognitive ability matters, as do non-cognitive factors such as motivation, hard work, and the learning ecosystem (discussed in Recommendation III). However, if the ultimate goal is subsequent sustained innovation, researchers must investigate whether there are other crucial characteristics that are currently overlooked. A properly formed research program will answer this question and elucidate the characteristics that define a future innovator. From this research, development of identification paradigms may be possible, encompassing a mosaic of cognitive and non-cognitive attributes that can help facilitate the discovery of more potential future innovators at an early age. Similarly, this research could shed new light on the role of spatial ability in STEM innovation. Finally, research should emphasize understanding how individual context (e.g., race/ethnicity, gender, socioeconomic status, age, locale) can alter the effectiveness of an identification strategy. We recommend the following three priorities for the research agenda:

1. Support research into identifying the cognitive and non-cognitive characteristics of future STEM innovators. Essential research questions include: What are the relative contributions of cognitive factors, such as domain-specific abilities (e.g., quantitative/mathematical, verbal, spatial), and non-cognitive attributes (e.g., motivation, leadership, resilience, creativity)? Is there a pattern of attributes unique to future STEM innovators, and how can schools teach creativity and innovative thinking?

2. Examine means for developing proper wide-scale assessment systems of all forms of abilities, particularly spatial ability and other overlooked talents (i.e., develop a research-based set of talent identification "best practices").

3. Investigate the optimal strategies to identify underrepresented individuals or groups that have the potential to become future STEM innovators. Particular attention should be given to examining the obstacles to identifying individuals with high potential and developing methods for overcoming them.

III: Foster a Supportive Ecosystem

Enhance the learning infrastructure support system for students by improving educator preparation and encouraging a culture that values academic excellence and innovation in families, local communities, schools, and the Nation.

Findings

Most learning occurs in a social context or ecosystem. This learning ecosystem includes teachers, principals and school administrators, guidance counselors, families, peers, neighborhoods, and a variety of other persons or factors that can assist or thwart academic development. The general attitude of these individuals and groups towards academic excellence can decidedly influence the learning ecosystem. Portions of our society often regard early intellectual achievement with ambivalence, and in some cases, outright hostility. This was not always the case. Equity in education is an empty concept without excellence. To ensure that our Nation continues to thrive in an increasingly competitive global economy, we must renew our efforts to create learning environments that nurture and celebrate intellectual achievement. The following findings support the policy actions and research agenda proposed below:

- Intellectually talented children and young adults can readily detect ambivalence, low expectations, or other negative attitudes within their learning ecosystem. Worse yet, sometimes these students face outright hostility. This often results in adverse consequences, such as poor self-efficacy, loss of motivation, and intellectual regression.[81]

To ensure that our Nation continues to thrive in an increasingly competitive global economy, we must renew our efforts to create a learning environment that nurtures and celebrates intellectual achievement.

- We should honor all of the gifts of our students, including academic talent, artistic abilities, inventiveness, and athletic accomplishments. In light of our Country's needs at both the national and regional/local levels, encouraging the pursuit of STEM careers by our talented students is particularly essential.

- Teachers are one of the most critical elements in the learning ecosystem. They must be well prepared and enthusiastic—characteristics that are necessary for the education of all students, not just the most talented. However, to teach potential STEM innovators, effective teachers must possess both exceptional subject content mastery and special pedagogical preparation for working with such students. Currently, most teachers receive very little preparation for working with or identifying talented students.[82] Research shows that teachers who are provided with this experience display a more positive attitude towards working with these students, are better skilled at identifying talent, and are more effective educators than those who do not receive such training.[83]

- Lack of administrative support, administrative or bureaucratic hurdles, and the absence of a positive school culture can discourage intellectual achievement, and in some cases, lead to students demonstrating regressive, oppositional behavior towards formal education.[84] Low expectations for some students, a lack of school leadership and teacher understanding of student potential and talent, and other negative attitudes and assumptions adversely affect the availability of programs and services for students advanced in the STEM areas. These factors also generate a lack of coherence and vertical alignment in the programming and interventions that *do* exist.

- Parents/guardians have the primary opportunity to instill in their children an expectation of excellence and a strong work ethic. Aversion or fear of certain subjects, such as mathematics (e.g., "math phobia"), is readily passed from teachers to students.[85] It is also likely that these anxieties are passed from parents/guardians to children. Parents/guardians can support future STEM innovators if they display a positive attitude towards learning and discovery to their children at the earliest ages. For instance, it should be just as unacceptable to be poor at math as it would be to be poor at reading.

- Motivation, achievement, and creativity are influenced by peer interactions. Connections with motivated, like-minded, and highly able peers can help foster a positive learning ecosystem and can be highly affirming.[86] Absence of this connection or peer hostility can quickly stifle early intellectual ambition. The Internet enables students to connect to both peers and learning opportunities unbounded by geography.

- Talent development serves both national and regional/local interests. However, resources to support this endeavor are predominantly derived from state and local agencies and possibly other funding sources, such as nonprofit entities.

Policy Actions

A. Create a national campaign aimed at increasing the appreciation of academic excellence and transforming stereotypes towards potential STEM innovators. The campaign should focus on individuals and groups involved in generating a positive learning support ecosystem, including educators, scientists and other STEM professionals, policy-makers, and the media. The media is critical to developing a culture that values STEM excellence. Learning opportunities should be available for parents/guardians about the importance of developing their children's abilities at the earliest ages, supporting their children's academic achievement and creative endeavors, and fostering a family culture that expects excellence. Prior STEM communication efforts, such as the National Academy of Engineering's 2008 report, *Changing the Conversation: Messages for Improving Public Understanding of Engineering*, could provide a useful blueprint for this campaign.[87]

B. Encourage the creation of positive school environments that foster excellence by providing professional development opportunities for teachers, principals, counselors, and other key school staff.

- For teachers, provide professional development in STEM instructional practices shown to improve achievement, creativity, and motivation among talented students.

- For principals and other administrators, provide professional development opportunities aimed at strengthening the leadership skills necessary to cultivate a supportive learning ecosystem for both teachers and *all* students.

- For counselors and other key school staff, provide professional development aimed at understanding the educational needs of talented students from diverse backgrounds and with diverse interests.

Attention should be given to professional development aimed at transforming negative attitudes and mindsets of educators and students regarding abilities and intelligence, and reversing underachievement in students with high potential.

C. Support the expansion of computing and communications infrastructure in elementary, middle, and high schools to foster peer-to-peer connections and collaborations, and direct connections with the scientific research community.

D. Hold schools, and perhaps districts and states, accountable for the performance of the very top students at each grade. Progress should be monitored for the top 10 percent and top 1 percent of students in each school using assessments that can adequately measure their performance (i.e., assessments must have an appropriately "high ceiling" to measure the full range of performance).[88] Schools and districts that demonstrate progress (e.g., increased student achievement, closing of achievement gaps at the "high end") should be rewarded. Conversely, sanctions should apply if these students are not making progress consistent with their talents and potential, just as it applies for other subgroups of students. We measure what is valued and their performance should be valued as well.

E. Have NSF, in partnership with the Institute of Education Sciences, hold a high-level conference to bring together researchers in the learning sciences, other scientists, education school administrators, current teachers and principals, and teacher professional associations to discuss teacher preparation and pedagogical best practices aimed at fostering innovative thinking in children and in young adults.

Research Agenda

Much work remains to understand fully the role of the learning support ecosystem and its relationship to future innovation. Individual ability and pattern of ability are clearly important as we describe above,[89] yet the development of an innovator does not take place in a vacuum. Instead, innovation occurs within a social context. A supportive learning environment can certainly enhance academic achievement, but more research is required to understand the characteristics of an effective ecosystem that can produce future leaders in STEM. Ability is present across all demographics, and educational opportunities and social context are likely contributors to achievement differences at the high end. Therefore, it is also vital to analyze specific contextual group indicators, such as cultural identity, gender, and socioeconomic status, that may have a disproportionate impact on underrepresented populations in STEM. We recommend the following three priorities for the research agenda:

1. Support research focused on identifying the characteristics of a learning ecosystem that facilitates near-term academic achievement and long-term production of innovation. Cross-cultural studies might be especially useful.

2. Investigate the individual contributions of, and the interplay between, the cognitive and non-cognitive attributes of an individual, and the learning ecosystem, in leading to future development of STEM innovators.

3. Study the impacts of self-perception, cultural identity, and external pressures (e.g., perceptions, stereotypes) on learning and future innovative achievement in STEM. Examine methods to overcome obstacles associated with these factors.

CONCLUSION

In November 1944, as World War II drew to a close, President Franklin Delano Roosevelt wrote in a letter to Vannevar Bush:

> *New frontiers of the mind are before us, and if they are pioneered with the same vision, boldness, and drive with which we have waged this war we can create a fuller and more fruitful employment and a fuller and more fruitful life.*[90]

Today, in the midst of another war and economic struggle, the National Science Board firmly believes that to secure our Nation's long-term prosperity we must identify and develop the talented young men and women who will become the next generation of STEM innovators. This endeavor begins with educational opportunities: the opportunity to achieve to the best of one's ability, the opportunity to think creatively, and the opportunity for the engagement and excitement that STEM provides. The rewards for our collective commitment will be numerous. The Board cannot improve upon the eloquent words of Vannevar Bush in his response to President Roosevelt:

> *The pioneer spirit is still vigorous within this Nation. Science offers a largely unexplored hinterland for the pioneer who has the tools for his task. The rewards of such exploration both for the Nation and the individual are great. Scientific progress is one essential key to our security as a nation, to our better health, to more jobs, to a higher standard of living, and to our cultural progress.*[91]

The Board firmly believes that the recommendations set forth in this report will help to ensure a legacy of continued prosperity for the United States, and engender a renewed sense of excellence in our education system, benefiting generations to come.

ENDNOTES

[1] Roosevelt, F. D. (1945). President Roosevelt's letter. In V. Bush, *Science–the endless frontier. A report to the President on a program for postwar scientific research* (p. 4). Washington, DC: U.S. Government Printing Office.

[2] Bush, V. (1945). *Science–the endless frontier. A report to the President on a program for postwar scientific research* (p. 23). Washington, DC: U.S. Government Printing Office.

[3] The National Commission on Excellence in Education. (1983). *A nation at risk: The imperative for educational reform.* Washington, DC: U.S. Department of Education. Retrieved from: *http://www2.ed.gov/pubs/NatAtRisk/index.html.*

[4] National Academy of Sciences. (2005). *Rising above the gathering storm: Energizing and employing America for a brighter economic future.* Washington, DC: The National Academies Press.

[5] Ibid. See Chapter 7: "What actions should America take in science and engineering higher education to remain prosperous in the 21st century?" pp. 162-181. Also, see the issue brief, "Attracting the most able US students to science and engineering," pp. 325-341.

[6] The *STEM Innovators* report is not primarily focused on what is classically thought of as "gifted and talented" (G&T), though the G&T scholarly community and research compendium have informed the present project. The Board recognizes that within the G&T scholarly community, the terms "gifts" or "gifted" and "talents" are not used interchangeably. However, for simplicity, the Board has elected to group these terms together.

[7] Lohman, D. F. (1994). Spatial ability. In R. J. Sternberg (Ed.), *Encyclopedia of intelligence* (p. 1000). New York, NY: Macmillan Press. In this chapter, the author defines spatial ability as, "the ability to generate, retain, retrieve, and transform well-structured visual images." Note: In the present report, spatial ability includes mechanical reasoning.

[8] Bush, V. (1945). *Science–the endless frontier. A report to the President on a program for postwar scientific research* (p. 18). Washington, DC: U.S. Government Printing Office.

[9] National Science Board. (2010). Industry, technology, and the global marketplace. In *Science and engineering indicators 2010.* Arlington, VA: National Science Foundation. Retrieved from: *http://www.nsf.gov/statistics/seind10/pdf/seind10.pdf.*

[10] Executive Office of the President. (2010). *A strategy for American innovation: Driving towards sustainable growth and quality jobs* (p. 4). Washington, DC: Office of Science and Technology Policy, National Economic Council. Retrieved from: *http://www.whitehouse.gov/sites/default/files/microsites/20090920-innovation-whitepaper.pdf.*

[11] Council on Competitiveness. (2007). *Competitive index: Where America stands* (p. 10). Washington, DC: Author. Retrieved from: *http://www.compete.org/images/uploads/File/PDF%20Files/Competitiveness_Index_Where_America_Stands_March_2007.pdf.*

[12] 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.

[13] Baldi, S., Jin, Y., Skemer, M., Green, P. J., & Herget, D. (2007). *Highlights from PISA 2006: Performance of U.S. 15-year-old students in science and mathematics literacy in an international context* (NCES 2008–016) (pp. 44, 49). National Center for Education Statistics, Institute of Education Sciences. Washington, DC: U.S. Department of Education. Retrieved from: *http://nces.ed.gov/pubs2008/2008016.pdf.* Note: The rank number represents the combination of OECD and non-OECD jurisdictions.

[14] Gonzales, P., Williams, T., Jocelyn, L., Roey, S., Kastberg, D., & Brenwald, S. (2008). *Highlights from TIMSS 2007: Mathematics and science achievement of U.S. fourth- and eighth-grade students in an international context* (NCES 2009-001 Revised) (p. 16). National Center for Education Statistics, Institute of Education Sciences. Washington, DC: U.S. Department of Education. Retrieved from: *http://nces.ed.gov/pubs2009/2009001.pdf.*

[15] Ibid.

[16] Zumeta, W., & Raveling, J. (2002). *The best and brightest: Is there a problem here?* (pp. 4-6). Washington, DC: Commission on Professionals in Science and Technology. Retrieved from: *http://www.cpst.org/BBIssues.pdf.* In this analysis, "highest achievers" refers to U.S. citizens scoring over a 750 on the GRE quantitative scale. The authors caution that these data are limited because "they are based on individuals' responses on the GRE registration questionnaire as to their intended field of graduate study, not on their actual enrollment behavior." (See p. 4).

[17] Lowell, B. L., Salzman, H., Bernstein, H. H., & Henderson, E. (2009). *Steady as she goes? Three generations of students through the science and engineering pipeline.* Paper presented at Annual Meetings of the Association for Public Policy Analysis and Management Washington, DC on November 7, 2009. Retrieved from: *http://www.heldrich.rutgers.edu/uploadedFiles/Publications/STEM_Paper_Final.pdf.* In this report, for the high school-to-college transition point, "highest performers" refers to high school students scoring in the top quintile of the SAT or ACT (pp. 9-10). The data showing a decline in the numbers of highest-achieving students enrolling in a STEM major or completing college with a STEM degree are shown in Figure 1 (p. 17). According to the data, there was a 14.9 percent decline between the 1992/97 cohort and the 2000/05 cohort. For further discussion regarding the high school-to-college transition point, see pp. 16-20.

[18] National Science Board. (2003). *The science and engineering workforce – realizing America's potential* (NSB-03-69). Arlington, VA: National Science Foundation. Retrieved from: *http://www.nsf.gov/nsb/documents/2003/nsb0369/nsb0369.pdf.*

[19] National Science Board. (2010). *Science and engineering indicators 2010: Appendix tables* (pp. 128-130). Arlington, VA: National Science Foundation. Retrieved from: *http://www.nsf.gov/statistics/seind10/pdf/at02.pdf.* See Table 2-35, "First university degrees, by selected region and country/economy: 2006 or most recent year."

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[21] National Science Board. (2010). Science and engineering labor force. In *Science and engineering indicators 2010* (chapter 3, p. 52). Arlington, VA: National Science Foundation. Note: Foreign-born workforce data for 2003 are located in Table 3-24. Retrieved from: *http://www.nsf.gov/statistics/seind10/pdf/seind10.pdf.*

[22] Wai, J., Lubinski, D., & Benbow, C. P. (2009). Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance. *Journal of Educational Psychology, 101,* 817-835.

[23] Ibid.

[24] For a discussion on college-age demographics, see: National Science Board. (2010). Higher education in science and engineering. In *Science and engineering indicators 2010* (chapter 2, p. 13). Arlington, VA: National Science Foundation. Retrieved from: *http://www.nsf.gov/statistics/seind10/pdf/seind10.pdf.* Also, see: Hussar, W. J., & Bailey, T. M. (2008). *Projections of education statistics to 2017* (NCES 2008-078). National Center for Education Statistics, Institute of Education Sciences. Washington, DC: U.S. Department of Education. Retrieved from: *http://nces.ed.gov/pubs2008/2008078.pdf.*

[25] National Science Board. (2010). Higher education in science and engineering. In *Science and engineering indicators 2010* (chapter 2, p. 24). Arlington, VA: National Science Foundation. Retrieved from: *http://www.nsf.gov/statistics/seind10/pdf/seind10.pdf.* Also, see Appendix Table 2-28.

[26] Business Roundtable. (2008). *Tapping America's potential: The education for innovation initiative* (p. 5). Washington, DC: Author. Retrieved from: *http://www.eric.ed.gov/ERICDocs/data/ericdocs2sql/content_storage_01/0000019b/80/1b/ad/71.pdf.*

[27] Bush, V. (1945). *Science–the endless frontier. A report to the President on a program for postwar scientific research.* Washington, DC: U.S. Government Printing Office. Quote originates from the Vannevar Bush Committee on Discovery and Development of Scientific Talent, p. 25.

[28] For example, seven Intel Science Talent Search finalists have been awarded the Nobel Prize, two have earned the Fields Medal, and 30 have been elected to the National Academy of Sciences. For more awards and honors of Intel Science Talent Search finalists, see: Society for Science & The Public. *Alumni honors. http://www.societyforscience.org/sts/alumni.*

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[30] The Council of the State Directors of Programs for the Gifted & The National Association for Gifted Children. (2010). *State of the states in gifted education: National policy and practice data 2008-2009.* Washington, DC: Author. Methodology note: 47 out of 50 states responded to the 2008-2009 questionnaire. Of those, the responses of 45 states were considered complete.

[31] U.S. Department of Education. *Fiscal Year 2010 Budget Summary – May 7, 2009. http://www.ed.gov/about/overview/budget/budget10/summary/edlite-section4.html.*

[32] Some NSF programs, such as the *Graduate Research Fellowships Program* and *NSF Scholarships in Science, Technology, Engineering, and Mathematics*, provide support for talented individuals at the undergraduate, graduate and post-doctoral levels.

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[36] Wyner, J. S., Bridgeland, J. M., & DiIulio, J. J. (2007). *Achievement trap: How America is failing millions of high-achieving students from lower-income families* (p. 11). Landsdowne, VA: Jack Kent Cooke Foundation. Retrieved from: *http://www.civicenterprises.net/pdfs/jkc.pdf.*

[37] Ibid. For a discussion of the authors' methodology, refer to p. 8. For a graphical representation of the educational disparities among high achievers, see p. 6.

[38] Ibid., p. 12.

[39] Plucker, J. A., Burroughs, N., & Song, R. (2010). *Mind the (other) gap! The growing excellence gap in K-12 education.* Center for Evaluation and Education Policy. Bloomington, IN: Indiana University School of Education. Retrieved from: *https://www.iub.edu/~ceep/Gap/excellence/ExcellenceGapBrief.pdf.* This report examines the achievement gap—or what the authors call the "excellence gap"—based on gender, socioeconomic status, race/ethnicity, and English language proficiency. For data analysis purposes, whether the achievement gap at the high end is widening, stable, or narrowing depends on how the top cohort is defined. For example, gaps among those reaching the "advanced" level in mathematics on the NAEP are generally widening, while gaps among those reaching the 90th percentile in mathematics on the NAEP are generally stable and in some cases narrowing. However, even if these gaps are narrowing, the authors point out that the rate of advancement of the underserved groups is so slow that it would require several decades to close them. See pp. 4-13 for a discussion on NAEP national data, and pp. 13-15 for NAEP state data. See pp. 15-18 for a discussion on the use of proficiency level cut-points (e.g., below basic, basic, proficient, advanced) compared to the use of percentiles (e.g., 90th percentile).

[40] Ibid., p. 6.

[41] See the following four references for an examination of the issue of educational achievement gaps: 1) Reardon, S. (2008). *Differential growth in the black-white achievement gap during elementary school among high- and low-scoring students* (Working Paper 2008-7). Stanford, CA: Institute for Research on Education Policy & Practice, Stanford University. Retrieved from: *http://www.stanford.edu/group/irepp/cgi-bin/joomla/docman/differential-growth-in-the-black-white-achievement-gap-reardon/download.html.* 2) Hanushek, E. A., & Rivkin, S. G. (2009). Harming the best: How schools affect the black-white achievement gap. *Journal of Policy Analysis and Management, 28,* 366-393. 3) Donovan, M. S., & Cross, C. T. (2002). *Minority students in special and gifted education.* National Research Council. Committee on Minority Representation in Special Education. Division of Behavioral and Social Sciences and Education. Washington, DC: National Academy Press. 4) Gándara, P. (2005). *Fragile futures: Risk and vulnerability among Latino high-achievers.* Princeton, NJ: Policy Evaluation and Research Center, Educational Testing Service. Retrieved from: *http://www.ets.org/Media/Research/pdf/PICFRAGFUT.pdf.*

[42] See the following three references regarding the underrepresentation of African American, Hispanic, and Indian/Native Alaskan students in gifted classrooms, AP classes, and achievement gaps at the "high end.": 1) Gándara, P. (2005). *Fragile futures: Risk and vulnerability among Latino high-achievers.* Princeton, NJ: Policy Evaluation and Research Center, Educational Testing Service. Retrieved from: *http://www.ets.org/Media/Research/pdf/PICFRAGFUT.pdf.* 2) Learning Point Associates. (2004). *All students reaching the top: Strategies for closing academic achievement gaps.* Naperville, IL: North Central Regional Educational Laboratory. Retrieved from: *http://www.ncrel.org/gap/studies/allstudents.pdf.* 3) Hoffman, K., & Llagas, C. (2003). *Status and trends in the education of blacks* (NCES 2003–034). Project Officer: T. D. Snyder. National Center for Education Statistics. Washington, DC: U.S. Department of Education. Retrieved from: *http://nces.ed.gov/pubs2003/2003034.pdf.*

[43] The White House, Office of the Press Secretary. (2009). *Remarks by the President on the 'educate to innovate' campaign.* Speech given by U.S. President, Barack Obama, on November 23, 2009. Retrieved from: *http://www.whitehouse.gov/the-press-office/remarks-president-education-innovate-campaign.*

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[45] Farkas, S., & Duffet, A. (2008). Results from a national teacher survey. In S. Farkas, A. Duffet, & T. Loveless (Eds.), *High-achieving students in the era of NCLB* (pp. 49-82). Washington, DC: Thomas B. Fordham Institute. Retrieved from: *http://www.edexcellence.net/doc/20080618_high_achievers_part2.pdf.*

[46] For a discussion on teacher training and talented students, see: The Council of the State Directors of Programs for the Gifted & The National Association for Gifted Children. (2010). *State of the states in gifted education: National policy and practice data 2008-2009* (pp. 38-41). Washington, DC: Author. Also, see: Archambault, F. X., Jr., Westberg, K. L., Brown, S., Hallmark, B. W., Emmons, C., & Zhang, W. (1993). *Regular classroom practices with gifted students: Results of a national survey of classroom teachers* (RM93102). Storrs, CT: The National Research Center on the Gifted and Talented, University of Connecticut. Retrieved from: *http://www.gifted.uconn.edu/nrcgt/reports/rm93102/rm93102.pdf.*

[47] Archambault, F. X., Jr., Westberg, K. L., Brown, S., Hallmark, B. W., Emmons, C., & Zhang, W. (1993). *Regular classroom practices with gifted students: Results of a national survey of classroom teachers* (RM93102). Storrs, CT: The National Research Center on the Gifted and Talented, University of Connecticut. Retrieved from: *http://www.gifted.uconn.edu/nrcgt/reports/rm93102/rm93102.pdf.* Sixty-one percent of approximately 7300 randomly selected third and fourth grade teachers in public and private schools in the United States reported that they had never had any training in teaching gifted students.

[48] National Science Board. (2007). *Moving forward to improve engineering education* (NSB-07-122). Arlington, VA: National Science Foundation. Retrieved from: *http://www.nsf.gov/pubs/2007/nsb07122/nsb07122.pdf.*

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[51] Ibid.

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younger students the opportunity for educational acceleration is supported by the following: The Council of the State Directors of Programs for the Gifted & The National Association for Gifted Children. (2010). *State of the states in gifted education: National policy and practice data 2008-2009.* Washington, DC: Author.

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literature concerning the factors that influence the attitudes of educators towards talented students, see: Bégin, J., & Gagné, F. (1994). Predictors of attitudes toward gifted education: A review of the literature and blueprints for future research. *Journal for the Education of the Gifted, 17,* 161-179.

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APPENDIX I

NSB-08-82
August 13, 2008
Revised February 4, 2010

CHARGE

COMMITTEE ON EDUCATION AND HUMAN RESOURCES EXPERT PANEL DISCUSSION ON PREPARING THE NEXT GENERATION OF STEM INNOVATORS[1]

Purpose

The National Science Board (Board) Committee on Education and Human Resources (CEH) is charged to undertake a study to fulfill the goal articulated in the Board's *National Science Board National Action Plan for Addressing the Critical Needs of the U.S. Science, Technology, Engineering and Mathematics* (STEM) *Education System* (NSB-07-114) to enhance "the Nation's ability to produce a numerate and scientifically and technologically literate society and to increase and improve the STEM education workforce." In approving its STEM Action Plan, the Board recognized that "Strategies for producing the next generation of innovators are not explicitly addressed in this action plan and will require subsequent study."

An *ad hoc* Task Group of CEH will lead the study whose purpose will be to identify strategies for increasing the number of STEM innovators in the next generation, and to develop recommendations for how the National Science Foundation, and possibly other Federal entities, might engage in fostering the development of the next generation of STEM innovators and in conducting rigorous research to better understand this process. As part of its effort, the Board will sponsor a two-day expert panel discussion on this topic and produce a white paper from this expert group with recommendations for consideration by the Board.

Statutory Basis

NATIONAL SCIENCE BOARD (42 U.S.C. Section 1863) SEC. 4(j) (2) The Board shall render to the President and to the Congress reports on specific, individual policy matters related to science and engineering and education in science and engineering, as the Board, the President, or the Congress determines the need for such reports.

Link to National or NSF Policy Objective

The Nation needs both financial resources and STEM talent to drive our highly technological and knowledge-based economy. The Board has argued in a number of its recent policy reports that the United States is too dependent on importing STEM talent from other countries, rather than

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[1] "Innovators" are being defined here as those individuals who have developed the expertise to become leading STEM professionals, and might even have become the creators of significant breakthroughs or advances in scientific and technological understanding - some of which may have completely changed research fields and/or might be patentable, for example.

nurturing a sufficient pool of this talent through our own educational system.[2] Other organizations and entities have also addressed issues related to STEM innovators, including the recent report of the National Mathematics Advisory Panel.[3] The President's American Competitiveness Initiative, the America COMPETES Act legislation, and the National Academies report, *Rising Above the Gathering Storm*, all recognize the importance of STEM talent to our economy. It would be appropriate for NSF, with a mission that encompasses both the development of STEM excellence (e.g., the NSF Graduate Fellowships) and equity (e.g., the Math and Science Partnerships program) to take a lead toward enabling our Nation to make headway on the dual objectives of global economic competitiveness and educational equity in STEM and to develop a road map for how schools, organizations outside of schools, and universities can challenge talented students during their scientifically formative years—adolescence and early adulthood—and recommend a research program to rigorously study their effectiveness.

Topics for Study

An expert panel discussion would involve a range of goals, such as:

- Identifying strategies for nurturing the talents of those individuals in adolescence and early adulthood who are likely to become the next generation of high-level STEM professionals and innovators.

- Exploring the possible existence of pools of potential talent in our society that currently are overlooked, under-developed, and under-utilized, but who could become a source of adults productive in STEM and who could fuel innovation in this country.

- Creating a research agenda on effective means for nurturing and developing the STEM talent in youth and early adulthood in order to accelerate the STEM productivity and creativity of such individuals over their careers.

- Suggesting and encouraging development of policies that could help ensure a strong pipeline of STEM talent and nurture innovation in the STEM workforce.

Logistics

The National Science Board Office will be the focal point for providing all aspects of Board support for this Board activity; coordinating NSF, the involvement of other agencies and institutions; and utilizing contractual or NSB Office staff resources to support events in connection with this Board-sponsored activity.

An agenda and a comprehensive list of potential participants for the two-day expert panel discussion will be developed with input from Board Members, NSF management, and other knowledgeable sources in the broader STEM research and education community.

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[2] Recent Board policy reports addressing this subject include the Companion to *Science and Engineering Indicators (SEI) 2008, Research and Development: Essential Foundation for U.S. Competitiveness in a Global Economy* (NSB-08-3), the Companion to *SEI 2006, America's Pressing Challenge—Building a Stronger Foundation*; the Companion to *SEI 2004, An Emerging and Critical Problem of the Science and Engineering Labor Force* (NSB-04-7), *Moving Forward to Improve Engineering Education* (NSB-07-122), and *The Science and Engineering Workforce—Realizing America's Potential* (NSB-04-69).

[3] *Final Report of the National Mathematics Advisory Panel*, March 2008, Department of Education.

CEH leadership

NSB/CEH will recommend full Board approval of the appointment of an *ad hoc* Task Group of CEH to provide oversight for, and actively engage in, this activity, on behalf of the CEH Committee with membership including: Drs. Camilla Benbow, John Bruer, José-Marie Griffiths, Louis Lanzerotti, and Diane Souvaine.

Product

The final output from this activity will be a concise set of Board-approved recommendations to NSF (and perhaps to other Federal entities), informed by a white paper capturing the results of the expert panel discussion and reflecting input from NSF and other agency expert staff, written background materials addressing these issues, and comments from interested communities on initial, Board-approved draft recommendations.

Schedule

A final, concise report will be submitted to the Board for approval and publication by summer 2010.

Audience

In addition to the President, Congress, and NSF:

- Federal agencies involved in STEM education
- State and local organizations and individuals involved or interested in STEM education
- Educational and professional organizations with interests in STEM education
- Employers of STEM-educated workers

APPENDIX II

Expert Panel Discussion Participants (August 23-25, 2009)

The Honorable Arne Duncan, U.S. Secretary of Education (Keynote Address)

National Science Board Members (in alphabetical order)

Dr. Arden L. Bement, Jr., Director, National Science Foundation and NSB Member *ex officio*
Dr. Camilla P. Benbow, Member; Patricia and Rodes Hart Dean of Education and Human Development, Peabody College, Vanderbilt University
Dr. John T. Bruer, Member & Chairman of the Committee on Education and Human Resources; President, The James S. McDonnell Foundation
Dr. Patricia D. Galloway, Vice Chairman, National Science Board; Chief Executive Officer, Pegasus Global Holdings, Inc., Cle Elum, Washington
Dr. José-Marie Griffiths, Member; Dean and Professor, School of Information and Library Science; Director of Biomedical Informatics, TraCS Institute, School of Medicine, University of North Carolina, Chapel Hill
Dr. Louis J. Lanzerotti, Member; Distinguished Research Professor of Physics, Center for Solar Terrestrial Research, Department of Physics, New Jersey Institute of Technology
Dr. Douglas D. Randall, Member; Professor and Thomas Jefferson Fellow, University of Missouri, Columbia
Dr. Diane L. Souvaine, Member; Department Chair and Professor of Computer Science, Tufts University
Dr. Kathryn D. Sullivan, Member; Director, Battelle Center for Mathematics and Science Education Policy, John Glenn School of Public Affairs, Ohio State University, Columbus
Dr. Craig R. Robinson, Acting Executive Officer, National Science Board and National Science Board Office Director

Panelists/discussants (in alphabetical order)

Dr. Michael J. Cima, Professor of Engineering, Massachusetts Institute of Technology; Director, Lemelson-MIT Invention and Innovation Center
Dr. Nicholas Colangelo, Director, The Connie Belin & Jacqueline N. Blank International Center for Gifted Education and Talent Development, University of Iowa
Dr. Diane C. DiEuliis, Assistant Director, Life Sciences, Office of Science and Technology Policy
Ms. Patricia Johnson, Javits Gifted and Talented Students Education Program, U.S. Department of Education
Mr. Dean Kamen, President, DEKA Research & Development
Dr. Ken Kotovsky, Professor and Director of Undergraduate Studies in Psychology, Carnegie Mellon University
Dr. David F. Lohman, Professor of Educational Psychology, University of Iowa
Dr. David Lubinski, Professor of Psychology, Peabody College; Co-Director, Study of Mathematically Precocious Youth
Dr. Cora B. Marrett, Deputy Director (acting), National Science Foundation
Dr. Stephanie Pace Marshall, Founding President of the Illinois Mathematics and Science Academy and founding President of the National Consortium for Specialized Secondary Schools of Mathematics, Science and Technology
Ms. Zipporah A. Miller, Associate Executive Director, Professional Programs and Conferences, National Science Teachers Association

Dr. Arthur P. Molella, Director, Lemelson Center for Invention and Innovation, National Museum of American History, Smithsonian

Dr. Diana G. Oblinger, President and Chief Executive Officer, Educause

Dr. Diana Rhoten, Program Director, Knowledge Institutions; Research Director, Digital Media and Learning, Social Science Research Council

Dr. Ann Robinson, Professor of Education and founding Director of the Center for Gifted Education, University of Arkansas at Little Rock; 2008-2009 President, National Association for Gifted Children

Dr. Robert Root-Bernstein, Professor of Physiology, Michigan State University

Dr. R. Keith Sawyer, Associate Professor, Department of Education, Washington University

Dr. Larisa V. Shavinina, Professor of Project Management & Innovation, Department of Administrative Sciences, Université du Québec en Outaouais (UQO), Canada

Dr. Sally Goetz Shuler, Executive Director, National Science Resource Center

Dr. Rena F. Subotnik, Director, Center for Psychology in Schools and Education, American Psychological Association

Dr. Joyce VanTassel-Baska, Director, Center for Gifted Education, The College of William and Mary

Dr. Jo Anne Vasquez, Vice President and Program Director Teacher & Curriculum Initiatives, Helios Education Foundation

Dr. Frank C. Worrell, Professor, University of California Berkeley; Faculty Director, Academic Talent Development Program; Director of Research and Development, California College Preparatory Academy

Mr. Joshua Wyner, Senior Vice President (Policy), National Consortium for College Completion

Dr. Lea Ybarra, Executive Director, Center for Talented Youth, Johns Hopkins University

Student Lunch Panel (in alphabetical order)

Richard Li, River Hill High School, Howard County, Maryland, Class of 2010
Elena Perry, Richard Montgomery High School, Montgomery County, Maryland, Class of 2010
Andrew Das Sarma, Montgomery Blair High School, Montgomery County, Maryland, Class of 2011
Louis Wasserman, University of Chicago, Class of 2012
Dr. Alex Wissner-Gross, Environmental Fellow, Harvard University

Additional online resources relating to the August 23-25, 2009 expert panel discussion can be found at the following URL: ***http://www.nsf.gov/nsb/meetings/2009/0824/index.jsp***

APPENDIX III

NSB/CEH-09-06
August 25, 2009

EXPERT PANEL DISCUSSION ON PREPARING THE NEXT GENERATION OF STEM INNOVATORS

FINAL AGENDA

Sunday, August 23

6:00 – 8:30 **Welcome Discussion & Dinner**
Dan & Brad's restaurant, Arlington VA

~6:45-7:15 **Overview: What is the State of the Field?**
Summary of gifted and talented education, innovation, creative thinking, learning sciences and the current state of our educational system with regard to these topics
Presenter: **Dr. Joyce VanTassel-Baska**, Director, Center for Gifted Education, The College of William and Mary

7:15-7:30 Reaction: **Dr. Rena Subotnik**, Director, Center for Psychology in Schools and Education, American Psychological Association

7:30-8:30 Discussion

Monday, August 24

8:00 **Welcome**

Dr. Patricia D. Galloway, Vice Chairman, National Science Board
Dr. John T. Bruer, Chairman, Committee on Education and Human Resources (CEH), STEM Innovators Task Group, National Science Board
Dr. Camilla P. Benbow, Lead, STEM Innovators Task Group, Committee on Education and Human Resources, National Science Board

8:15 **Board Process and Participant Introductions**

8:20 – 3:00 **Session I: Characterization and Development of Future STEM Innovators**

8:20-9:50 **Cognitive and non-cognitive characteristics of an innovator**
Guiding questions: What are some of the defining characteristics of an innovator and potential future innovators? How important are attributes such as ability, interest, determination, and inquisitiveness? How can theories

of cognition, motivation, and other non-cognitive factors be applied to educational practices for fostering innovation? What do research on inquiry in science education and theories of intelligence and innovation add to the discussion? What research needs to be done to determine the most effective means (both cognitive and non-cognitive) for identifying STEM talent in youth and early adulthood? What are the implications for policy?
Moderator: **Dr. Camilla P. Benbow**

Panelists:

- **Dr. David Lubinski**, Professor of Psychology, Peabody College; Co-Director, Study of Mathematically Precocious Youth
- **Dr. R. Keith Sawyer**, Associate Professor, Department of Education, Washington University
- **Dr. Larisa V. Shavinina**, Professor of Project Management & Innovation at the Department of Administrative Sciences, Université du Québec en Outaouais (UQO), Canada

9:50 **Break**

10:00 -12:00 **Developing STEM innovators through the education system**
Guiding questions: Once we understand the characteristics of a potential innovator, how do we 1) initiate the innovation process and 2) develop a possible STEM innovator in order to increase the likelihood of productivity over an entire career? What kinds of schools or formal learning settings are best for motivating students to become STEM innovators? How can we expand the kinds of opportunities that have promising evidence on effectiveness to broader populations of students? How do we raise the ceiling of potential for the exceptionally gifted and/or motivated student? How can we best anticipate future learning environments? Why do talent losses occur at critical transition points in the educational system? How can higher education best partner with other institutional components of the innovation life cycle? What are the policy implications?
Moderator: **Dr. Diane L. Souvaine**

Panelists:

- **Dr. Nicholas Colangelo**, Director, The Connie Belin & Jacqueline N. Blank International Center for Gifted Education and Talent Development, University of Iowa
- **Dr. Stephanie Pace Marshall**, founding President of the Illinois Mathematics and Science Academy and founding President of the National Consortium for Specialized Secondary Schools of Mathematics, Science and Technology
- **Dr. Robert Root-Bernstein**, Professor of Physiology, Michigan State University
- **Dr. Lea Ybarra**, Executive Director, Center for Talented Youth, Johns Hopkins University

12:00 **Lunch**: Perspective from current and former students

Lunch will be provided to invited panelists and discussants only

Guiding questions: What has been your experience in the education system? Do/did you feel sufficiently challenged? Are you aware of and encouraged by your school to take advantage of enrichment opportunities, such as laboratory research partnerships, summer programs, or other opportunities such as accelerated learning? What was the most important factor in seeding your interest in the STEM disciplines? What was the biggest challenge you faced or what was the most significant negative force in terms of your education? How would you change it? What helped transform your creative potential into reality? What hinders it?

Moderator: **Dr. Kathryn D. Sullivan**

Panelists:

Introduction: **Dr. Carol Blackburn**, Johns Hopkins University

- **Richard Li**, River Hill High School, Class of 2010
- **Elena Perry**, Richard Montgomery High School, Class of 2010
- **Andrew Das Sarma**, Montgomery Blair High School, Montgomery County, Maryland, Class of 2011
- **Louis Wasserman**, University of Chicago, Class of 2012
- **Dr. Alex Wissner-Gross**, Environmental Fellow, Harvard University

1:15-3:15 **Informal learning, cyber-learning and innovative education**

Guiding questions: What kinds of informal learning settings are effective for motivating students to develop the skills needed to become a potential STEM innovator? How can we expand the kinds of opportunities that have promising evidence on effectiveness to more and broader populations of high-potential students? How can new technologies be harnessed to serve the development and possibly enhance productivity of future STEM innovators? How can these emerging technologies be used to foster collaboration, enhance networking across multiple disciplines, and generate improvements in both informal and traditional learning environments that might nurture STEM innovation potential? What are the policy implications?

Moderator: **Dr. José-Marie Griffiths**

Panelists:

- **Dr. Arthur P. Molella**, Director, Lemelson Center for Invention and Innovation, National Museum of American History, Smithsonian
- **Dr. Diana G. Oblinger**, President and CEO of EDUCAUSE
- **Dr. Diana Rhoten**, Program Director, Knowledge Institutions; Research Director, Digital Media and Learning, Social Science Research Council

3:15 **Break**

3:30 – 5:30 **Session II: Identifying and Nurturing Under-developed STEM Talent**

Identifying under-developed pools of STEM talent and the community role in fostering achievement
Guiding questions: How can we best identify and nurture pools of potential STEM talent in our society that currently are overlooked, under-developed, and under-utilized, but could become a source of adults productive in STEM and could fuel innovation in this country? What role does the community (parents, teachers, local businesses) play in nurturing, supporting and motivating students? Do ethnically or geographically distinct subgroups of students learn differently? What role does cultural background play in talent development? What are the policy implications?
Moderator: **Dr. Louis J. Lanzerotti**

Panelists:

- **Dr. Rena F. Subotnik**, Director, Center for Psychology in Schools and Education, American Psychological Association
- **Dr. David F. Lohman**, Professor of Educational Psychology, University of Iowa
- **Dr. Frank C. Worrell**, Professor, UC Berkeley. Faculty Director, Academic Talent Development Program, Director of Research and Development, California College Preparatory Academy
- **Mr. Joshua Wyner**, Senior Vice President (Policy), National Consortium for College Completion

5:30 **Dinner on your own**

Tuesday, August 25

8:00 – 8:30 **Keynote Address**
Introduction: Dr. Arden L. Bement, Jr., Director, NSF
Keynote Address: The Honorable Arne Duncan, U.S. Secretary of Education

8:30 – 10:30 **Session III: The Products of Innovation**

The innovation ecology and entrepreneurship
Guiding questions: There are many factors external to the individual involved with innovation. Innovations do not occur in a vacuum, and an innovation can change its own environment. What does the research say about innovation as a product of individuals or a product of groups? How would the collaborative process factor in the learning processes associated with innovation? What can we learn from industry and business regarding innovation and entrepreneurship that would be helpful in improving formal and informal learning environments? How can lessons learned from these groups improve policy-making?
Moderator: **Dr. John T. Bruer**

Panelists:

- **Dr. Michael J. Cima**, Sumitomo Electric Industries Professor of Engineering, MIT; Director, Lemelson-MIT Invention and Innovation Center
- **Mr. Dean Kamen**, President, Deka Research & Development
- **Dr. Kenneth Kotovsky**, Professor and Director of Undergraduate Studies in Psychology, Carnegie Mellon University

10:30 **Break**

10:45 – 12:45 **Session IV: Perspectives on Government Education Programs and Policy**

Existing government education programs, program assessment and effective policy design and implementation

Guiding questions: What are we currently doing for innovators in terms of programs and policies? What types of policy recommendations are ideal in terms of implementation? Can state/local government education policy inform Federal Government policy recommendations? How do we define success in STEM education (e.g., PISA scores, other metrics) and how does STEM education success in the U.S. compare internationally? What can we learn from successful international STEM education systems, particularly with regard to high-ability students?

Moderator: **Dr. Camilla P. Benbow**

Panelists:

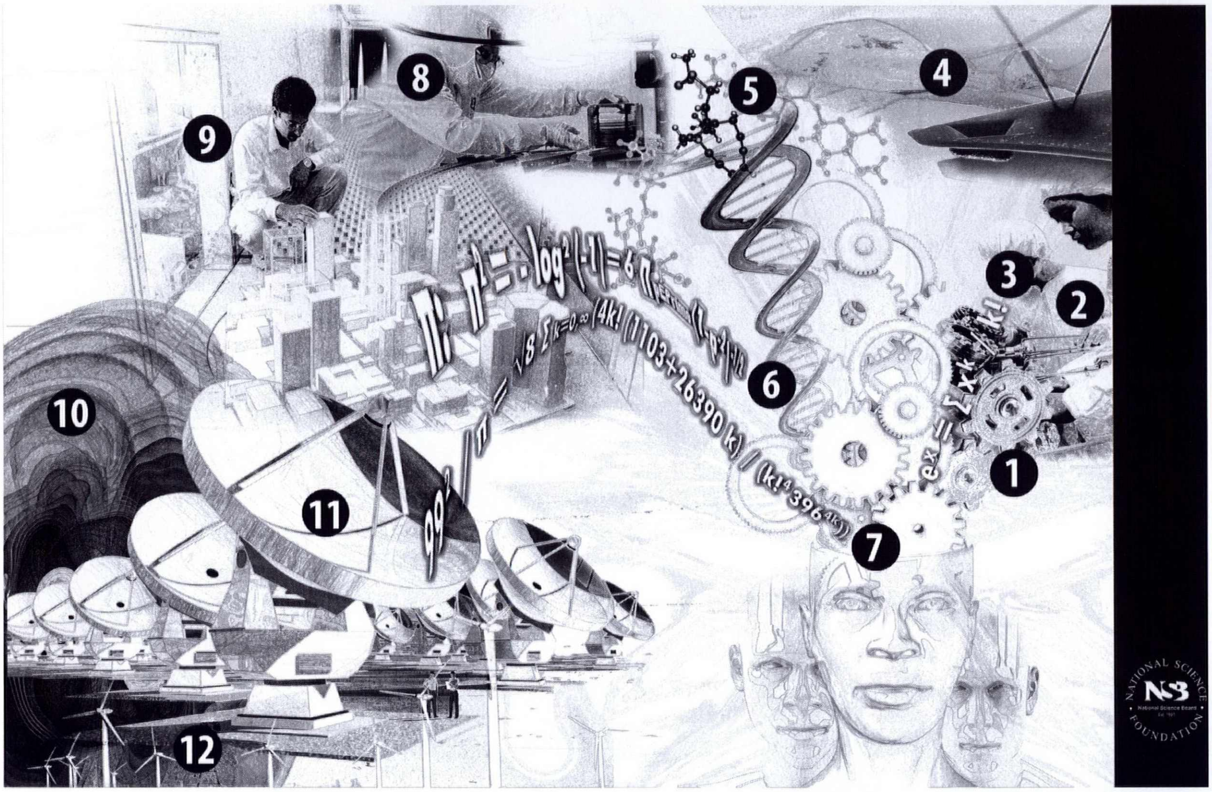
- **Dr. Diane C. DiEuliis**, Assistant Director, Life Sciences, OSTP
- **Ms. Patricia Johnson,** U.S. Department of Education, Javits Gifted and Talented Students Education Program
- **Dr. Cora B. Marrett,** Deputy Director (acting), NSF

12:45 **Adjourn**

Additional Discussion Participants

- **Ms. Zipporah A. Miller**, Associate Executive Director, Professional Programs and Conferences, National Science Teachers Association
- **Dr. Ann Robinson**, Professor of Education, founding Director of the Center for Gifted Education, University of Arkansas at Little Rock; 2008-2009 President, National Association for Gifted Children
- **Dr. Sally Goetz Shuler**, Executive Director, National Science Resource Center
- **Dr. Jo Anne Vasquez**, Vice President and Program Director Teacher & Curriculum Initiatives, Helios Education Foundation

COVER IMAGE CREDITS



1) These miniature gears, developed by researchers at AT&T Bell Laboratories, are about the size of a human hair and are driven by air forced through their ports. Micromechanics is one of the emerging technologies supported by the National Science Foundation (NSF).

   Credit: AT&T Bell Labs

2) A West Virginia University electrical engineering graduate research assistant explains the use of molecular beam epitaxy for the growth of nanostructures to a physics undergraduate. The equipment was upgraded using funding from the NSF EPSCoR (Experimental Program to Simulate Competitive Research) activity, provided through West Virginia EPSCoR during a previous Research Infrastructure Improvement grant. The research being performed was funded by NSF.

   Credit: West Virginia University - WVNano (Date of image: 2004)

3) Sir Isaac Newton (1643-1727; England) made revolutionary advances in mathematics, optics, dynamics, thermodynamics, acoustics and celestial mechanics. In addition to several other important advances in analytic geometry, his mathematical works include the Binomial Theorem, his eponymous numeric method, the idea of polar coordinates, and power series for exponential and trigonometric functions. His equation $ex = \sum xk / k!$ has been called the most important series in mathematics.

4) A composite of scanning electron microscope images showing biological force microscopy, developed by NSF-funded researchers at Virginia Polytechnic Institute and Virginia State University.

   Credit: Dr. Steven Lower, University of Maryland; and Dr. Michael Hochella, Virginia Tech

5) A molecular model of esperamicin A1, an enediyne. Enediynes are naturally occurring molecules—commonly called biological warheads—for their ability to bind to and split tumor's DNA backbones. Computations were performed on the National Center for Supercomputing Applications (NCSA) SGI Origin2000 supercomputer, purchased primarily with funds from NSF.

Credit: Images by Steven Feldgus; simulation completed using computational resources provided by the NCSA [Structure comes from Kumar, R. A., Ikemoto, N., & Portel, D. J. (1997). *J. Mol. Biol, 265*, 173-186.]

6) Leonhard Euler (1707-1783; Switzerland) made decisive contributions in all areas of mathematics; he gave the world modern trigonometry. Along with Lagrange, he pioneered the calculus of variations. He was the most prolific mathematician in history and the best algorist. Some of Euler's greatest formulae can be combined into curious-looking formulae for π: $\pi 2 = -\log 2(-1) = 6 \prod p \in \mathrm{Prime}(1-p-2)-1/2$.

7) Srinivasa Ramanujan Iyengar (1887-1920; India) was a self-taught prodigy who lived in a country distant from his mathematical peers, and suffered from poverty and malnutrition. Despite these limitations, Ramanujan is considered one of the greatest geniuses ever and produced 4000 theorems or conjectures in number theory, algebra, and combinatorics. Because of its fast convergence, an odd-looking formula of Ramanujan is often used to calculate π: $99^2 / \pi = \sqrt{8} \sum k=0,\infty \ (4k! \ (1103+26390 \ k) \ / \ (k!4 \ 3964k))$.

8) A technician at Texas Instruments processes wafers containing computer microchips. The Maricopa Advanced Technology Education Center (MATEC) effects change in technician education through the creation of competency-based curricula, diverse and effective professional development programs, and replicable workforce development models. MATEC is funded in part by a grant from NSF's Advanced Technological Education (ATE) program.

Credit: Photo from ATE Centers Impact 2008-2010, *http://www.atecenters.org* (Date of image: 2009)

9) A model of downtown Minneapolis, Minnesota, is prepared for testing in the boundary layer wind tunnel at the University of Minnesota's St. Anthony Falls Laboratory (SAFL). The test will study the effects of wind on structures, including stress on windows, heat loss due to leaks and poor air conditioning and ventilation system performance, as well as the effects of wind on pedestrians. Support for the design and construction of the wind tunnel was made through an NSF grant.

Credit: Courtesy Pat Swanson, St. Anthony Falls Laboratory, University of Minnesota

10) This numerical simulation is part of a series depicting orbiting black holes and represents the first time that three-quarters of a full orbit has been computed. The simulations show the merger of two black holes and the ripples in space-time—known as gravitational waves—that are born of the merger. These simulations were created on the NCSA Itanium Linux Cluster (It) by researchers from the Max Planck Institute for Gravitational Physics (Albert Einstein Institute) in Potsdam, Germany, and visualized by Werner Benger of the Albert Einstein Institute (AEI) and the Konrad-Zuse-Zentrum in Berlin. NSF support was used for this project.

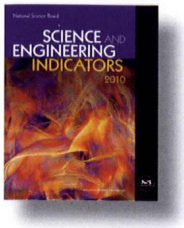
Credit: Simulations by Max Planck Institute for Gravitational Physics (Albert-Einstein-AEI); visualization by Werner Benger, Zuse Institute, Berlin and AEI. The computations were performed on NCSA's It.

11) The image represents an artist's conception of the antennas for the Atacama Large Millimeter Array (ALMA). The construction and operation of ALMA will be funded through a joint agreement between NSF and the European Southern Observatory. NSF will execute the project through the National Radio Astronomy Observatory (NRAO). ALMA will be an array of 64, 12-meter radio antennas that will work together as one telescope to study millimeter and sub-millimeter wavelength light from space. These wavelengths of the electromagnetic spectrum, which cross the critical boundary between infrared and microwave radiation, hold the key to understanding such processes as planet and star formation, the formation of early galaxies and galaxy clusters and the detection of organic and other molecules in space.

12) This image of wind turbines contrasts the past—a wind pump used to draw water from farm wells for cattle, and the future—modern wind turbines. The wind turbines are part of the Cedar Creek wind farm in Colorado. The farm includes more than 250 turbines and generates roughly 300 megawatts of energy. As wind energy grows in importance, scientists at the National Center for Atmospheric Research (NCAR) are studying how wind turbines and farms interact with the atmosphere, and how their output can be better predicted and managed.

Credit: University Corporation for Atmospheric Research (Date of image: unknown)

National Science Board Recent Publications



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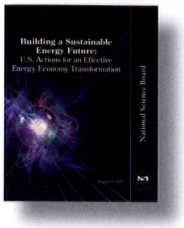

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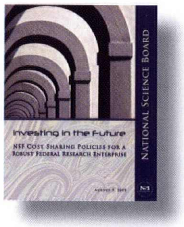

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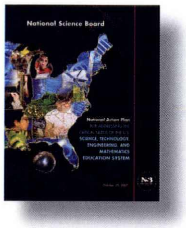

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