THE OPPORTUNITY EQUATION

Transforming Mathematics and Science Education for Citizenship and the Global Economy

CARNEGIE CORPORATION OF NEW YORK | INSTITUTE FOR ADVANCED STUDY

Commission on Mathematics and Science Education

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Commission on Mathematics and Science Education

MATHEMATICS AND SCIENCE EDUCATION AS AN "ENGINE OF DEMOCRACY" FOR AMERICA'S FUTURE

Historically, mathematics was considered the Queen of the sciences. From the work of Euclid to Ptolemy to Newton to Descartes, mathematics has laid the foundation for modern science. And from the time of the Renaissance on, science itself has been central to the development of modern society and the primary engine of global progress. Successes achieved in almost every field of human endeavor—medicine, transportation, commerce, communication, engineering, security and defense, to name just a few—owe an incalculable debt to the evolution of math and science. Science, whether physical, biological, natural, applied, or theoretical, has helped to plumb the depths of the oceans, send men and women into space, and create computers that are among the most influential tools humankind has ever invented.

Yet while all this is true, and the general public is certainly quick to both praise and adapt the latest technologies, in recent years the worldwide spread of technological advances has not resulted in an equally robust appreciation of mathematics and science among Americans. Now, however, in the post-Cold-War world of the 21st century, when we have entered into a new phase of globalization characterized by knowledge-based economies and fierce competition, the United States can no longer afford not to be fully engaged with math and science and their application to teaching and learning.

It was in this spirit that, in 2007, Carnegie Corporation of New York joined with the Institute for Advanced Study to create a commission, comprised of some of our nation's most distinguished mathematicians, scientists, educators, scholars, business leaders, and public officials, to assess not only the current state of math and science education in the U.S. but also how to enhance the capacity of our schools and universities to generate innovative strategies across all fields that will increase access to high-quality education for every student in every classroom. If we believe, as the great education reformer Horace Mann did, that "education is the engine of democracy," then the strength and progress of both American society and our democracy depend on our ability to mobilize around this work, with clear goals and great determination.

Since the beginning of the last century, Carnegie Corporation and its sister organizations, including the Carnegie Institution for Science, the Carnegie Endowment for International Peace, Carnegie Mellon University, The Carnegie Foundation for the Advancement of Teaching, and the Carnegie Council for Ethics in International Affairs, have helped to advance American education and the world of ideas. Now, with this effort to enrich math and science education in the U.S., the Corporation is gratified to partner with the Institute for Advanced Study, the home of such luminaries as Abraham Flexner, Albert Einstein, J. Robert Oppenheimer, and Hetty Goldman, and which today, continues to be among the great driving forces of math and basic science research in our nation. Together, we are pleased to present *The Opportunity Equation*, the report of the Carnegie Corporation of New York-Institute for Advanced Study Commission on Mathematics and Science Education. It is a clarion call to renew our commitment to revitalize our educational system by creating change for the future that is rooted in knowledge infused with a deep understanding of math and science.

Vartan Gregorian
President
Carnegie Corporation of New York

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Commission on Mathematics and Science Education

STRENGTHENING INNOVATION CAPACITY TO TRANSFORM MATHEMATICS AND SCIENCE EDUCATION

In 2007, Carnegie Corporation of New York joined with the Institute for Advanced Study to create a Commission composed of distinguished mathematicians, scientists, educators, public officials, and business and nonprofit leaders. The Commission was charged with assessing the current state of math and science education in the U.S. and developing actionable recommendations for the country to fully prepare American students in mathematics and science so that every student has the opportunity for a productive adult life in our rapidly changing world.

The Commission recognized that there have been important calls for action over the past few years, including the National Research Council's *Rising Above the Gathering Storm* and the National Center on Education and the Economy's *Tough Choices or Tough Times*. These reports, and others, raised alarms about the danger that the United States was losing its competitive edge and had urged the nation to make specific improvements to our educational system. Coming from different sectors and representing a diversity of perspectives, the Commission members came to rapid agreement that the United States cannot make the necessary improvements to mathematics and science education by focusing exclusively on mathematics and science learning; instead, we must also make fundamental changes to the nation's schools and strengthen the innovation capacity of the educational system. The Commission has combed the field for ideas and practices that are already operating effectively on the ground and has given careful consideration to other recent recommendations and calls for action. The Commission's work confirms that strong and promising examples exist, as does a growing national consensus that change is needed.

American students need to know more than they typically learn in today's schools, and they need complex skills that enable them to apply their knowledge. Mathematics and science are essential parts of the foundational knowledge that all students need to acquire, and learning in those disciplines enables students to acquire skills and understanding that are increasingly essential to their ability to succeed in higher education and in careers. All students need a sophisticated working knowledge of math and science; their schools must not fail them in this.

Enabling that sort of learning will require fundamental change throughout our schools and school systems. To unleash innovation and build a stronger foundation for learning by all American students, we need to provide schools with frameworks

and resources that make specific gains in mathematics and science possible: fewer, clearer, higher standards and more sophisticated assessments, an increased flow of teaching talent and better human capital management, and more effective school and system designs. We need to challenge schools to change, give them the tools and incentives to do so, and hold them accountable according to the highest, most equitable, and most comprehensive measure available: student learning in mathematics and science.

Commission members believe that our schools can meet this challenge—but we also believe that they cannot do so without the structural underpinnings proposed in this report. We believe that a national mobilization will be necessary, involving all the sectors represented on the Commission itself and beyond. We are heartened by the keen interest in education that is so evident in the Obama administration, many state governments, and a wide network of policymakers, businesses, unions, and nonprofit organizations. The task of assembling this report has not been easy, but we conclude the process with a sense of optimism.

We hope that *The Opportunity Equation* resonates widely and inspires action. We sincerely thank the members of the Carnegie Corporation of New York-Institute for Advanced Study Commission on Mathematics and Science Education for their dedicated and thoughtful service and trust that they will continue to serve as leaders in bringing excellence and equity to American education.

Phillip Griffiths – Commission Chair
Professor of Mathematics and Former Director
Institute for Advanced Study

Michele Cahill – Commission Co-Chair
Vice President, National Programs and Program Director, Urban Education
Carnegie Corporation of New York

CARNEGIE CORPORATION OF NEW YORK | INSTITUTE FOR ADVANCED STUDY
Commission on Mathematics and Science Education

EXECUTIVE SUMMARY

The United States must mobilize for excellence in mathematics and science education so that all students — not just a select few, or those fortunate enough to attend certain schools — achieve much higher levels of math and science learning. Over the coming decades, today's young people will depend on the skills and knowledge developed from learning math and science to analyze problems, imagine solutions, and bring productive new ideas into being. The nation's capacity to innovate for economic growth and the ability of American workers to thrive in the global economy depend on a broad foundation of math and science learning, as do our hopes for preserving a vibrant democracy and the promise of social mobility for young people that lie at the heart of the American dream.

Our nation needs an educated young citizenry with the capacity to contribute to and gain from the country's future productivity, understand policy choices, and participate in building a sustainable future. Knowledge and skills from science, technology, engineering, and mathematics—the so-called STEM fields—are crucial to virtually every endeavor of individual and community life. All young Americans should be educated to be "STEM-capable," no matter where they live, what educational path they pursue, or in which field they choose to work.

For the United States, the "opportunity equation" means transforming American education so that our schools provide a high-quality mathematics and science education to every student. The Commission believes that change is necessary in classrooms, schools and school districts, and higher education. The world has shifted dramatically — and an equally dramatic shift is needed in educational expectations and the design of schooling.

Excellent mathematics and science learning for all American students will be possible only if we "do school differently" in ways that place math and science more squarely at the center of the educational enterprise. We need new school models that push the limits of practice at both ends of the instructional spectrum: re-engaging our most disconnected students in academically rigorous math and science education and placing them on pathways to graduation and postsecondary education, and providing opportunities for the most successful students in math and science to accelerate beyond what is traditionally available in high school.

THE COMMISSION AND ITS WORK

Coming from different sectors and representing a diversity of perspectives, the members of the Commission came to agreement that the United States cannot make the necessary improvements to mathematics and science education by focusing exclusively on mathematics and science learning. Rather, the United States will need to give at least equal weight to driving fundamental change to the nation's schools and to strengthening the innovation capacity of the educational system. The Commission has combed the field for ideas and practices that are already operating effectively on the ground and has given careful consideration to other recent recommendations and calls for action. The Commission's work indicates that strong and promising examples exist, as does a growing national consensus that change is needed.

A COMPREHENSIVE MOBILIZATION PLAN

The Commission has crafted a comprehensive program of action—one that will require commitments from many quarters, including the federal government, states, schools and school districts, colleges and universities, unions, businesses, nonprofit organizations, and philanthropy. A detailed set of recommendations lays out a practical, coordinated plan, and describes what each constituency can do to raise mathematics and science achievement for all American students. Recommendations are presented in four priority areas:

- **Higher levels of mathematics and science learning for all American students.** Mobilize the nation for excellence and equity in mathematics and science education. Place mathematics and science at the center of education innovation, improvement, and accountability.
- **Common standards in math and science that are fewer, clearer, and higher, coupled with aligned assessments.** Establish common standards that are fewer, clearer, and higher and that guide instructional improvement in mathematics and science. Develop sophisticated assessments and accountability mechanisms that, along with common standards, stimulate instructional improvement and innovation in mathematics and science
- **Improved teaching and professional learning, supported by better school and system management.** Increase the supply of well-prepared teachers of mathematics and science at all grade levels by improving teacher preparation and recruitment. Improve professional learning for all teachers, with an eye toward revolutionizing math and science teaching. Upgrade human capital management throughout U.S. schools and school systems toward ensuring an effective teacher for every student, regardless of socio-economic background.
- **New designs for schools and systems to deliver math and science learning more effectively.** Build high expectations for student achievement in mathematics and science into school culture and operations as a pathway

to college and careers. Enhance systemic capacity to support strong schools and act strategically to turn around or replace ineffective schools. Tap a wider array of resources to increase educational assets and expand research and development capacity.

Significant improvement in mathematics and science learning will be much more likely if the American people, especially young people, understand what is possible and demand it. The Commission therefore urges a national mobilization to raise awareness and galvanize the nation for change. Through strategic partnerships, the Carnegie Corporation of New York, the Institute for Advanced Study, and other organizations (including many whose leaders have served on the Commission) are taking action and encouraging broad participation. Resources to inform and strengthen this important work, along with tools for planning, tracking, and aligning efforts around the country, are available online at www.OpportunityEquation.org.

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Commission on Mathematics and Science Education

A MOMENT OF URGENCY AND OPPORTUNITY

The United States must mobilize for excellence in mathematics and science education so that all students — not just a select few, or those fortunate enough to attend certain schools — achieve much higher levels of math and science learning. Over the coming decades, today's young people will depend on the skills and knowledge developed from learning math and science to analyze problems, imagine solutions, and bring productive new ideas into being. The nation's capacity to innovate for economic growth and the ability of American workers to thrive in the global economy depend on a broad foundation of math and science learning, as do our hopes for preserving a vibrant democracy and the social contract with young people that lies at the heart of the American dream: *Invest in yourself, work hard and learn, and you will have opportunities for rewarding work and meaningful choices about your future.*

What kind of schools and systems of education does America need to transform mathematics and science education and deliver it equitably and with excellence to all students?

What kind of schools and systems of education does America need to transform mathematics and science education and deliver it equitably and with excellence to all students? The Commission believes that the magnitude of the challenge demands transformative change in classrooms, schools, and education systems. Educators, students, parents, leaders of universities, museums, and the business and professional communities, scientists and mathematicians, and public officials at all levels will need to embrace a new understanding that the world has shifted dramatically—and that an equally dramatic shift is needed in educational expectations and the design of schooling. As a society, we must commit ourselves to the proposition that all students can achieve at high levels in math and science, that we need them to do so for their own futures and for the future of our country, and that we owe it to them to structure and staff our educational system accordingly.

The United States needs an educated young citizenry with the capacity to contribute to and gain from the country's future productivity, understand policy choices, and participate in building a sustainable future. The Commission's own survey research suggests that America's young people care deeply about problems such as global warming, world hunger, and poor health and want to be involved in solving them. We know that math and science are fundamental to sound decision making and to an ever-widening range of careers in nearly every sector, from technology and research to business, teaching, health, community development,

and human services. We also know that, in today's economy, the sharp division between preparing for higher education and preparing for a career has effectively disappeared. Knowledge and skills from science, technology, engineering, and mathematics—the so-called STEM fields—are crucial to virtually every endeavor of individual and community life. All young Americans should be educated to be "STEM-capable," or to possess those skills and knowledge, no matter where they live, what educational path they pursue, or in which field they choose to work.[1]

To meet the dual demands of equity and excellence in mathematics and science education, the United States will need to pursue a coordinated agenda that includes re-crafting the standards and upgrading the assessments that guide what happens in our classrooms, deploying the talents of our educators more effectively, and aligning our schools and school systems with the task of bringing the diversity of American students to high levels of math and science learning. To make the most of our efforts, we will need to structure all those changes to leverage and reinforce one another for national impact and to learn through ongoing research. The Commission recommends that, as a guiding principle, we take every opportunity to build math and science learning into all school reform initiatives, at every grade level, for every student.

Previous commissions and task forces have called attention to the disappointing performance of American students in mathematics and science and proposed a range of thoughtful, well-reasoned strategies for improvement. The work of the Carnegie-IAS Commission on Mathematics and Science Education confirms many of those earlier findings and seconds a number of recommendations that are already on the table.[2] Yet the Commission also urges close attention to some key prior questions: *What could truly effective math and science education for all young Americans look like today? How can a new approach to math and science learning ignite the curiosity, ambition, innovation, and problem-solving potential of a rising generation of Americans? How can we mobilize people, policy, and resources to achieve real gains?*

Having asked those questions as part of its own deliberations, the Commission concludes that reform in mathematics and science will be possible only if we "do school differently" in ways that emphasize the centrality of math and science to educational improvement and innovation. Significant, sustainable improvement will be much more likely if the American people, and especially young people, understand what is possible and demand it. Excellent, relevant math and science learning should be understood as a public good and an entitlement—one that is not being realized for too many of our students. Furthermore, the Commission proposes that, for the nation, holding ourselves accountable for raising math and science achievement for all students will be the means by which we finally achieve transformative change in our educational system.

[1] **Science, technology, engineering, and mathematics have been called the "STEM fields" in many recent reports and discussions. In this report, the Commission primarily uses "mathematics and science," which should be understood to include knowledge and skills from the fields of engineering and technology.**

[2] **See pages 4–5 for influential recent reports whose recommendations align with the recommendations of the Carnegie-IAS Commission.**

This is a moment of urgency and opportunity, a chance to close the gap between the current state of educational achievement and the educational system we need. Messages for change are coming from employers and philanthropists; teachers and school leaders; education and civil rights advocates; local, state, and national policymakers; and the Obama administration. There's a great deal of good work happening on the ground, nationally and in many states and localities. To seed a national mobilization, the Commission has combed the field for ideas and practices that are already working, at least on a small scale. Highlighted throughout this report are models that could be expanded, customized, or combined as necessary to meet local needs or conditions and studied as they mature. There is much to be gained by leveraging successful strategies, bringing coherence to endeavors that have often been treated separately, and weaving them into a unified plan for raising math and science achievement for all American students.

The Commission offers first steps toward a long-range vision, one that takes into account the practical challenges of upgrading math and science education, makes sense for the schools we have today and hope to achieve tomorrow, and puts us on a path toward delivering the mathematics and science learning our young people need. Strong math and science education for all American students is our best strategy; as the Commission has learned, the tools for implementing that strategy are within our grasp.

As a guiding principle, we should take every opportunity to build math and science learning into all school reform initiatives, at every grade level, for every student.

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Commission on Mathematics and Science Education

MATHEMATICS AND SCIENCE LEARNING AND SCHOOL REFORM:

MOBILIZING FOR A UNIFIED AGENDA

The Carnegie-IAS Commission endorses a unified agenda involving fundamental school system reform and a rigorous overhaul of mathematics and science education. Our analysis suggests that those efforts are mutually dependent—that math and science learning will rise only if schools and instruction change profoundly, but also that schools are much more likely to improve if they tap the motivating power of science and math learning. Within that framework, the Commission's findings are consistent with those of several influential recent reports:

The Economic Impact of the Achievement Gap in America's Schools. 2009. McKinsey & Company.

- Highlights the significant and negative correlation between educational achievement gaps and national GDP. The data presented in this report underscore the dual national needs—and supports Commission recommendations—to close achievement gaps and raise achievement for all students to meet and exceed international benchmarks.

Benchmarking for Success. 2008. National Governors Association, Council of Chief State School Officers, Achieve.

- Addresses challenges and promising solutions to combat the international achievement gap. Findings in support of common and rigorous standards, better assessments, and improved human capital management with a focus on recruiting, training, and retaining the best teachers are particularly aligned with the Commission's recommendations.

Fostering Learning in a Networked World. 2008. National Science Foundation Task Force on Cyberlearning.

- Analyzes the challenges of preparing students with 21st century levels of understanding of technology and science. Its support for improved professional development for teachers around the use of technology, and for increased and strategic deployment of technology and instructional tools in the classroom, are particularly coherent with the Commission's recommendations.

Foundations for Success. 2008. National Mathematics Advisory Panel.

- Addresses the challenges of math achievement in the United States and highlights international achievement gaps in this area. Its support for improved and targeted recruitment of teachers and for the implementation of fewer, clearer, higher standards align with the Commission's recommendations.

Out of Many, One. 2008. Achieve, Inc.

- Presents an analysis of the college- and career-ready standards for English and mathematics in a selection of states. The findings, in alignment with Commission recommendations, recognize that "there is fundamental knowledge in English and mathematics that all graduates must know to succeed and that is not bound by state lines" and thus support common, rigorous, college- and career-ready standards for all students.

Building a STEM Agenda. 2007. National Governors Association.

- Highlights the challenges of supporting American global competitiveness and innovation, particularly in light of the fact that U.S. 12th and 8th grade students score below the OECD average on tests of math and science. Its recommendations for a multi-pronged strategy to spur improvement—including common, rigorous, and internationally benchmarked standards and aligned assessments; improved management of human capital with attention to STEM capacity; and improved accountability systems to track achievement—align with the Commission's recommendations.

Rigor at Risk. 2007. ACT.

- Highlights the negative impact of multiple and often low standards across high school core courses and the resulting depression of college readiness among far too many graduates. Its support for increased alignment between high school and college-level standards as a necessary component for raising achievement is coherent with the Commission's recommendations in this area.

Taking Science to School. 2007. National Research Council.

- Highlights the need to bring a much broader cohort of students to much higher levels of achievement in science. Its support for common and rigorous standards and aligned assessments and for targeted professional development in science teaching cohere with the Commission's focus on bringing all students to much higher levels of science knowledge and understanding and producing a STEM-literate citizenry.

Tough Choices or Tough Times. 2006. National Center on Education and the Economy.

- Considers the need to build student knowledge and skills to meet the needs of the 21st century global labor market. Its view that these skills are new, increasingly cognitive, and analytic and support for innovations in recruitment of teachers and in design and delivery of schools cohere with the Commission's recommendations in these areas.

Rising Above the Gathering Storm. 2005. National Research Council.

- Emphasizes the need to significantly improve science and technology capacity to maintain and increase national innovation. Its recommendations in support of dramatic increases in recruitment (and corresponding incentives) of science and math teachers, enlarging the STEM pipeline across high school and college, and increasing participation and retention in higher education STEM fields are all coherent with the Commission's recommendations.

Engaging Schools: Fostering High School Students' Motivation to Learn. 2004. National Research Council.

- Stresses the importance of organizing secondary schools to promote student engagement, especially for urban students. Its emphasis on structuring all aspects of school—including curriculum, instruction, and school organization—to engage students cognitively and emotionally is consistent with the Commission's recommendations for school design.

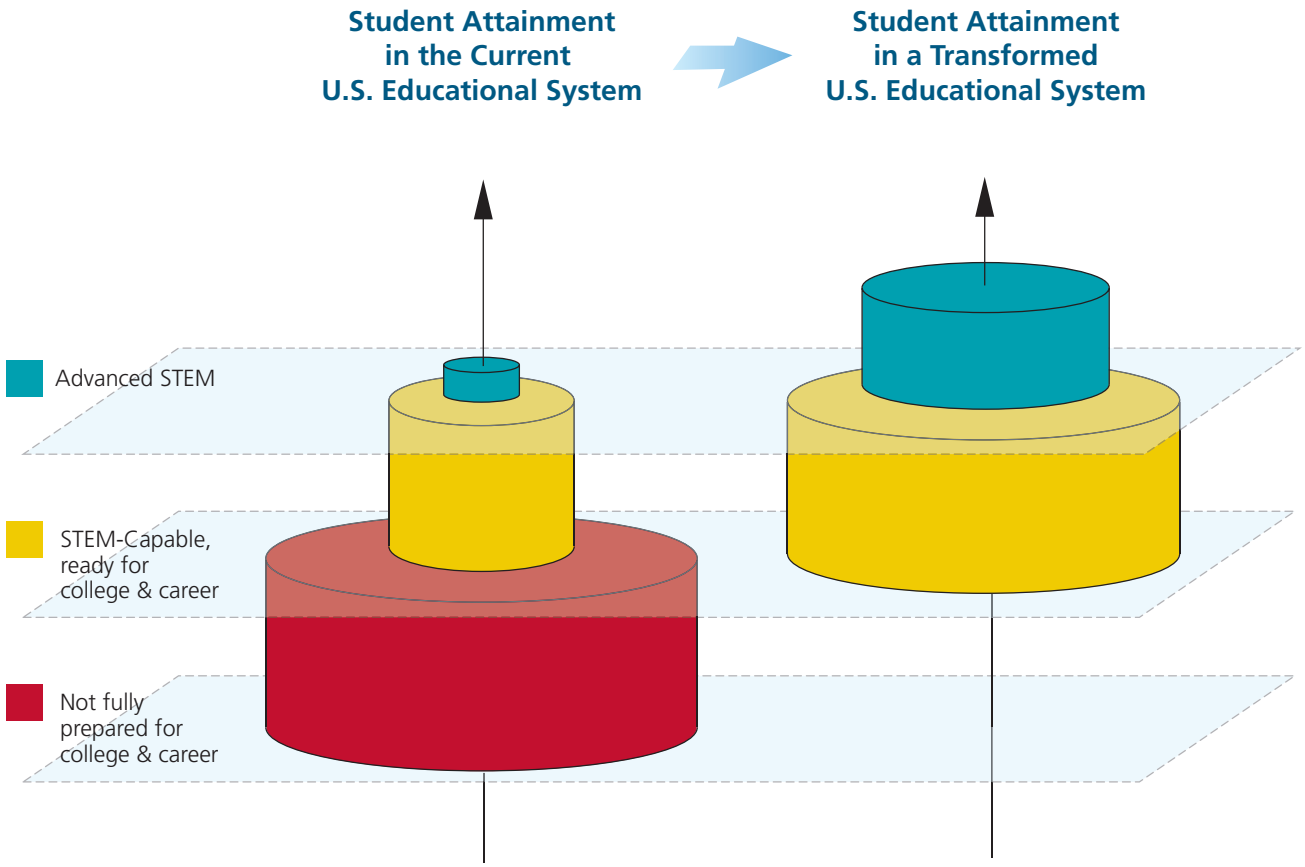
Adding It Up. 2001. National Research Council.

- Addresses the need to bring many more students to much higher levels of math achievement. Its recommendations regarding improved, capacity-driven standards and corresponding instructional and curricular reforms support the Commission's recommendations in these areas.

This is a moment of urgency and opportunity, a chance to close the gap between the current state of educational achievement and the educational system we need.

GOAL: MUCH HIGHER LEVELS OF MATHEMATICS & SCIENCE LEARNING FOR AMERICAN STUDENTS

The world has changed. In every sphere of life, Americans are finding that they need to know more and to learn continuously to keep pace with new demands. Our educational system needs to change, as well. Today, too few students get the preparation they need for the challenges of postsecondary education and an innovation- and knowledge-based global economy. A transformed educational system would raise levels of performance by all American students, providing them with a strong foundation for success in college and careers and enabling many more to pursue advanced training in the science, technology, engineering, and mathematics (STEM) fields.



EXCELLENCE AND EQUITY: MOBILIZING FOR MATH AND SCIENCE LEARNING

What would it take to change education to meet the future needs of the American people? Just as our nation once transformed its school system to enable the shift from an agricultural to an industrial economy, we must reinvent our educational system again today, this time for a rapidly changing and increasingly technological global economy.[3] Math and science learning belong at the center of that transformation.

Mathematics and science are essential components of a liberal education, the backbone of logic and analytic thinking from early childhood through the most advanced levels of learning across the academic disciplines. Science, technology, engineering, and mathematics enable us to understand the natural world, the built environment, systems of society, and the interactions among them that will determine the future of our nation and planet. Like literacy, math and science embody habits of mind and methods for discerning meaning that enable students to learn deeply and critically in all areas. Just as adults need math and science to understand the world and function within it, students need math and science to understand and master subjects such as history, geography, music, and art.

The Commission is not arguing that math and science are more important than other branches of learning: rather, we believe that mathematics and science education as currently provided to most American students falls far short of meeting their future needs or the needs of society. Further, we contend that mathematics and science—and science in particular—have received too little attention in recent rounds of school reform. Mathematics educator and Commission member Uri Treisman has recommended that schools "inject mathematics throughout the curriculum by ending its unnatural suppression from other subjects."[4] The Commission endorses this view and believes that the same counsel should be applied to science. We believe that the goal of improving math and science could sound a call for change that would reverberate throughout our schools and increase student learning in all areas. And we believe that bringing national resources, solutions, and policies to bear toward enabling all American students to be "STEM-capable" would help schools and districts to take up the challenge.

Good schools enable students to cultivate math and science skills from the earliest grades, supporting their learning as they master not just content but ways of knowing that are applicable in many areas of learning and life. Summarizing the goals of science learning in kindergarten through grade 8 in its seminal 2007 report *Taking Science to School*, for example, the National Research Council described four

[3] Claudia Goldin and Lawrence F. Katz (2008). *The Race between Education and Technology*, Harvard University Press; see especially chapter 3, "Skill-Biased Technological Change," and chapter 8, "The Race between Education and Technology."

[4] Personal communication to the Commission, November 25, 2008.

crucial capacities that all students should develop: knowing, using, and interpreting scientific explanations of the natural world; generating and evaluating scientific evidence and explanations; understanding the nature and development of scientific knowledge; and participating productively in scientific practices and discourse.[5] *Adding It Up*, the National Research Council's influential 2001 study of K-8 mathematics education, emphasized similarly foundational capacities: conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition.[6] These are core capacities that, if developed systematically from kindergarten through university for every student, would reduce the educational deficits that limit our nation's human capacity, producing what a recent report by McKinsey and Company termed "the economic equivalent of a permanent national recession."[7]

For today's students, math and science also open the door to understanding new technologies—a realm of interest that is crucial to our collective economic future but whose value has yet to be fully tapped by our educational system. Outside the classroom, evidence abounds that new media are powerful vehicles for motivating young people, capturing their imaginations, and inspiring them to strive for mastery.[8] In its 2008 report *Fostering Learning in a Networked World*, the National Science Foundation Task Force on Cyberlearning acknowledges that educational technology has not yet had the profound impact on American schools that has long been anticipated, but the Task Force also argues that "cyberlearning has reached a turning point where learning payoffs can be accelerated."[9] If so, the potential for offering students new and motivating avenues to build science, math, engineering, and technology knowledge is great.

The Commission urges schools to put greater emphasis on mathematics and science and to seek every opportunity to infuse other curricular areas with math and science content and methods. But schools alone cannot create a "science-and-math-rich" environment for young people. As a society, we must expand the walls of the traditional schoolhouse to encompass a much wider environment and set of resources. Math and science learning offer powerful points of intersection between schools and institutions such as museums, universities, research laboratories, businesses, and trade and professional associations. Organizations dedicated to science, engineering, and technology in particular are assets to the educational enterprise. Through programs like the National Science Foundation's Math and Science Partnership Network, they have become increasingly important partners to school systems, working closely with teachers and school system leaders to advance research and provide students with experiences that deepen their knowledge and enliven their understanding of the world.[10] National policies and resources could do more to promote partnerships that would bring new resources and momentum to transform mathematics and science learning for all students.

[5] **National Research Council (2007). *Taking Science to School: Learning and Teaching Science in Grades K-8*.**

[6] **National Research Council (2001). *Adding It Up: Helping Children Learn Mathematics*.**

[7] **McKinsey & Company (2009). *The Economic Impact of the Achievement Gap in America's Schools*.**

[8] **Pew Internet and American Life Project (2009). *Generations Online in 2009*.**

[9] **National Science Foundation Task Force on Cyberlearning (2008). *Fostering Learning in the Networked World: The Cyberlearning Opportunity and Challenge, A 21st Century Agenda for the National Science Foundation*.**

[10] **For the National Science Foundation Math and Science Partnership Network, see hub.mspnet.org.**

[11] **National Center on Education and the Economy (2006). *Tough Choices or Tough Times*, Jossey-Bass, P. 8. National Research Council (2005). *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*, P. 2.**

Math and science are calibrators for the depth, rigor, and relevance to students' interests and passions that our educational system must deliver far more reliably. When students succeed in math and science, they are by definition showing strong literacy skills in academic vocabulary, comprehension, and fluency, along with decision making and problem solving. Achievement in mathematics and science is therefore an indicator of effectiveness at every level: classroom, school, school system, college or university, state, and even larger components such as the nation's capacity to improve schools, educate teachers, ensure social mobility, and promote productivity. Raising the bar on math and science will set the bar high for every aspect of the education enterprise and every contributor to students' learning.

OBJECTIVES

- Mobilize the nation for excellence and equity in mathematics and science education
- Place mathematics and science at the center of education innovation, improvement, and accountability

DISCUSSION

Many Americans—business leaders and government officials, and also educators, parents, and even students—acknowledge the need for radical change in the way mathematics and science are taught and learned in most U.S. schools and colleges. Some calls for change have been motivated by a desire to restore American preeminence in technological innovation. The nation must act quickly, the argument goes, to increase the number of high-level U.S. science, math, and engineering graduates or forever be left behind.[11]

The Commission shares that concern and recognizes that the United States will always need top graduates in those fields, yet we are also persuaded by arguments that the new global economy demands higher levels of skill held by many more people. Nearly every worker will need to be STEM-capable, or knowledgeable about science and math, even beyond the professions that require specialized science, technology, engineering, or mathematics training; more jobs at more levels in fields such as health, law, business, and education will require science- and math-related skills; and the level of skill and knowledge demanded will be higher.

This reality presents an unprecedented challenge to our current educational system, and also an opportunity: What if we were to use the objective "excellent math and science education for all" as a lever for widespread school reform at the scale that is needed? Could a national mobilization for math and science bring unity of purpose to school improvement and drive the system to generate new designs and methods?

Math and science embody habits of mind and methods for discerning meaning that enable students to learn deeply and critically in all areas.

1. On mobilizing for equity and excellence in mathematics and science education

The Commission believes that the United States must use its resources wisely to ensure that *all* young Americans, including but not limited to those who aspire to high-level math and science degrees and careers, are well prepared by our schools and colleges to participate and thrive in a global economy, and that science and math skills are essential to that preparation. Further, we have confidence that American students and families agree with that assessment and would welcome efforts to improve—in quality and relevance, not just in courses required—the science and math education received by all American students.

As Commission member and Carnegie Corporation president Vartan Gregorian has noted, "the value of an education lies in its task to enhance men's and women's powers of rational analysis, intellectual precision and independent judgment, and in particular to encourage a mental adaptability, a characteristic which men and women sorely need, especially now, in an era of rapid change."[12] The emerging global marketplace is making those characteristics even more important, as shifts in the labor market indicate clearly. In 2007, for example, the Bureau of Labor Statistics projected that 54.7 million American jobs would open during the decade from 2004 to 2014, of which well over half (29.4 million) will require a college degree.[13] Moreover, the only job categories for which both demand and wages are continuing to grow are "non-routine analytic" positions, requiring good judgment, an ability to solve problems, and strong communications, information management, and synthesizing skills.[14]

Skills related to collaboration and systems integration are also growing in importance as the United States seeks to redefine its role as an incubator for innovation. As Hal Salzman, a labor analyst at the Urban Institute, explained to the Commission, economic productivity and growth depend on strong skills at many levels of the labor force. "Although innovating a better computer network server is important," he noted, "it is the legions of network administrators and technicians that affect how much of the potential productivity gains are realized from the technology."[15] Salzman believes that the United States should aim to be a "strong node" in a collaboration-oriented global marketplace and that "the United States is currently the best positioned country . . . to do this because of its history of openness, diversity, and free flow of knowledge, and home to companies that are now the leading navigators in the new global systems."

A common thread across these data is the increasingly determinative importance of educational attainment generally, and higher education specifically, to economic opportunity and national innovation. Labor economist Stephen Machin has observed that "the demand for education is still outstripping supply despite the rapid expansion of skill-biased technological change and globalization. So, the penalty for not having a good education level is rising."[16] By 2004, wage declines among high school graduates with no postsecondary education placed this group

[12] Vartan Gregorian (1997). Convocation address, Brown University.

[13] Bureau of Labor Employment Projections: stats.bls.gov/emp/emptabapp.htm.

[14] Richard Murnane and Frank Levy (2004). *The New Division of Labor*, Princeton University Press, chapter 3. Data presented by Andreas Schleicher of the Organization of Economic Cooperation and Development (OECD) on the results of its Programme for International Student Assessment (PISA) study of 2006.

[15] Hal Salzman (2007). "Globalization Shifts in Human Capital and Innovation: Policy for Collaborative Advantage & Implications for Education." Prepared for the Carnegie-IAS Commission on Mathematics and Science Education.

[16] Presented at the Sutton Trust/Carnegie Corporation Summit on Social Mobility, June 2-3, 2008.

[17] National Center for Education and the Economy (2006). P. 6.

[18] Organisation for Economic Co-Operation and Development (2008). *Education at a Glance*. P. 87, Table A3.2. oecd.org.

[19] Paul E. Lingenfelter, "More Student Success: A Systemic Solution," presented at the Carnegie Corporation-University of Minnesota Roundtable, January 9, 2009.

[20] President Barack Obama. Address to Joint Session of Congress, February 24, 2009.

for the first time below the middle 50 percent of family incomes in the United States, or below the middle class.[17]

The United States no longer leads the world in preparing young people through the attainment of college degrees. In 1995, the U.S. ranked second internationally in the percentage of college graduates in the population; by 2006, its relative position had declined.[18] The absolute percentage of college educated within the U.S. population remained steady at approximately 34 percent, while the share in countries including New Zealand, Finland, Denmark, the Netherlands, Norway, Sweden, and Japan increased. Globally, China and India remain far below the United States in percentage of college-educated adults, yet their absolute numbers are growing rapidly because of their large youth populations.

Paul E. Lingenfelter, president of State Higher Education Executive Officers, has argued that for the United States to be "second to none in degree attainment by 2025 requires 16 million more [bachelor's] degrees."[19] Lingenfelter observes that the United States will get to that objective only by achieving "equal college participation and success rates at every level of socio-economic status and academic ability" and increasing "educational expectations and attainment for average ability students." The shifting demographics and economic realities of the nation mean that we must better educate a more diverse range of students than ever before.

The Commission shares President Obama's conviction that "every American will need to get more than a high school diploma," for their own futures and the future of the country, and echoes his call for "every American to commit to at least one year or more of higher education or career training [at] a community college or a four-year school, vocational training or an apprenticeship."[20] To build the skills and knowledge required by the 21st century global labor market, our educational system must produce many more students who are "college-ready" and well prepared to succeed in undergraduate education. Then, because of the importance of math and science to students' futures as workers and citizens, colleges and universities must provide richer math and science learning to all and open wider avenues for students of all backgrounds with the interest and aptitude to pursue advanced degrees. In short, it is imperative that we raise educational attainment at both the bottom and the top, and close the gaps in opportunity that too often divide American students along lines of race, ethnicity, and socio-economic background.

In contemplating the implications of these trends and indicators for our country, the Commission takes encouragement from students' own views on math and science, as well as those of their parents. In fall 2008, the Commission undertook a sizeable national survey to explore attitudes toward math and science among the two crucial constituencies: adolescents in grades 8–10 and their parents. Digging deeper, the study team conducted in-depth focus groups with 8th and 10th graders and their parents in two urban areas. In both the survey and focus groups, the researchers made special efforts to understand the views of African-American and Latino students and parents.[21]

Colleges and universities must provide richer math and science learning to all and open wider avenues for students of all backgrounds to pursue advanced degrees.

Although the samples are too small to produce definitive national findings, the outcomes are intriguing, in part because they run counter to some conventional assumptions about how young people think about learning and achievement in mathematics and science. Overall, the results give strong reason to expect that students and parents will be receptive to calls for higher levels of math and science learning and to realistic proposals to improve math and science education for all students.

Substantial shares of both students and parents said that they understand the importance of math and science and see the need for stronger, more relevant math and science education. Overall, young people and their parents may be ahead of public perceptions in their openness to math and science learning and to improving the nation's educational performance in those areas. The study uncovered findings in several key areas:

- **High perceived importance of math and science.** Students and parents recognize the importance of math for their futures. Majorities of students believe that algebra (69 percent) and geometry (59 percent) will be important for their careers—and parents agree. Many students identified "data analysis" as an important skill for their futures—second only to English. Majorities also believe that science classes are at least somewhat important: 62 percent for biology, 59 percent for chemistry, and 59 percent for physics. These findings hold with slight variation across racial and ethnic groups.
- **Limited understanding of the connection between advanced courses and careers.** When students discussed their career ambitions, many did not connect their aspirations with required high school math and science coursework, suggesting a need to help students see the relevance of upper-level math and science coursework in secondary school and beyond.
- **Strong influence of teachers on student attitudes.** Students who rate their teachers highly are more likely to see math and science in their futures. Students and parents gave high marks to teachers who use engaging instructional practices: for example, in science, holding labs more than once a week and having students report findings to the class; in math, promoting multiple approaches to problem solving and helping students apply lessons to the real world.
- **Positive student views of math and science achievers.** Students do not, in general, hold negative stereotypes of peers who are good at math or science. They are much more likely to associate positive descriptors than negative ones to successful math and science students. For example, 42 percent said a successful math student is "hardworking," and 32 percent said "smart." Just 12 percent associate the word "nerdy" with a good science student.

[21] The survey and focus groups were conducted by Widmeyer Research and Polling. The survey consisted of a 20-minute interview of 977 students (8th to 10th grade) and their parents, for a total of 1,954 interviews. The sample included oversamples of African-American households (185 pairs, or 370 total) and Latino households (140 pairs, or 280 total). The weighted N size—accounting for oversamples—is 904 pairs (1,808 total). The survey was fielded from October 22 to November 4, 2008. Ten focus groups were conducted in Denver and Nashville, with participants recruited from the urban school district and surrounding suburban/exurban districts. The Denver research included two paired urban groups (non-Latino students and their parents), two paired suburban/exurban groups (students and their parents), and one group of urban Latino students. The Nashville research included two paired urban groups (non-African-American students and their parents), two paired suburban/exurban groups (students and their parents), and one group of urban African-American students. For more information on study methods and complete findings, see Widmeyer Research and Polling (April 2009). *Attitudes toward Math and Science Education among American Students and Parents*, prepared for the Carnegie-IAS Commission on Mathematics and Science Education. OpportunityEquation.org/go/widmeyer.

[22] Carol S. Dweck (2008). "Mindsets and Math/Science Achievement." Prepared for the Carnegie-IAS Commission on Mathematics and Science Education. Dweck demonstrates that student performance is influenced positively by students' belief that they have the capacity to learn math or science, and that teachers can support that mindset through instructional practice. OpportunityEquation.org/go/dweck.

- **Clear recognition that math and science can be learned by all—although one in four hold doubts.** Most parents and students understand that math and science skills can be learned and developed, and that doing well is not simply a matter of innate ability. Among students, 70 percent said that math ability is something people can learn and develop, versus 25 percent who said math ability is primarily innate.[22]

In short, young people and their parents recognize the importance of mathematics and science and see the value of high-quality instruction. A national mobilization for mathematics and science learning would make the need for change plain to all Americans and bring resources and commitment to the effort.

Young people and their parents may be ahead of public perceptions in their openness to math and science learning and to improving the nation's educational performance in those areas.

2. On placing mathematics and science at the center of education innovation, improvement, and accountability

With excellent, equitable mathematics and science at the center, schooling itself would look and feel different for nearly all American students. What is too often missing today for students at all levels is a focus on acquiring the reasoning and procedural skills of mathematicians and scientists, as well as a clear understanding of math and science as distinct types of human endeavor. Learning math and science from textbooks is not enough: students must also learn by struggling with real-world problems, theorizing possible answers, and testing solutions. Of central importance, the Commission is calling for a dramatic redefinition of science instruction, away from the current system in which students are generally being told about science and asked to remember facts, to one where students, beginning in the very early grades, learn how to think scientifically and become proficient in science—including acquiring its crucial problem-solving and inquiry skills.

Placing mathematics and science more squarely at the center of learning has the potential to transform schooling from the elementary grades through university. Schools and universities would feature an enhanced curriculum and instruction with active learning at its core, a more vital learning culture and leadership, new partnerships and resources, and higher expectations and pathways for students. A coordinated national effort would encourage wider adoption of successful practices, inspire new initiatives, and provide a framework for measuring their impact. It would also let us improve upon existing methods for replicating successful designs and practices to reach more states, districts, schools, educators, and students more rapidly.

Practically, a coordinated effort is challenging to carry off in an educational system as decentralized as ours. Yet several factors today are working in our favor—most notably, the keen interest of the federal Department of Education in linking education to national economic recovery and recent work by governors and state departments of education to strengthen the nation's education infrastructure by creating systems of academically rigorous common standards and assessments across many or all states.

The nation's schools are also benefiting from fresh influences that bode well for innovation and coordinated improvement. Over the past decade, education entrepreneurs have altered the marketplace for teacher recruitment, data management, professional development, and other services, changing the way many school districts do business and advancing the notion that old ways of carrying out core operations are not good enough. A resurgence in interest in teaching among young adults and career changers has brought an infusion of new talent, including new teachers with strong educational and career-related background in science, math, and technology, into our schools. Meanwhile, a wave of innovation has taken hold among leading museums and other "science-rich" and cultural institutions, some of which are actively redefining themselves as full partners in the education enterprise.[23] Public–private partnerships involving businesses and professional organizations have grown up around the country to improve science and math education and workforce development.

For a glimpse of what excellent, equitable mathematics and science education might look like in a transformed American educational system, the Commission sought out initiatives that exemplify the principles of excellence and equity and that are already using math and science to accelerate school improvement. We found evidence of several potentially powerful emerging practices:

- **Designing for equity—using math, science, and technology to motivate student engagement.** Math-and-science-themed schools have often been highly selective, but a new generation of schools with STEM themes are accepting students regardless of past academic achievement and preparing them for the challenges of the 21st century workplace. New Tech High School, in Napa, California, and the network of schools based on the New Tech model are examples.[24]
- **Infusing math and science across the curriculum to deepen student learning.** Cultivating science skills within literacy development can be a powerful way to build reading students' skills and learn science content at the same time. Programs that are pioneering this approach include the Seeds of Science/Roots of Reading program at the University of California-Berkeley and the University of Maryland's Concept-Oriented Reading Instruction (CORI).[25]
- **Expanding the repertoire of classroom strategies with hands-on math and science activities.** Duke University's Engineering K-PhD Program, led by engineer and Commission member Gary Ybarra, strengthens math and science learning in school and after-school programs through an engineering curriculum that emphasizes real-world problem-solving. Students work on projects involving energy sources, architecture, biotechnology, digital imaging, transportation, wireless communication, and other topics.[26]
- **Increasing the rigor of youth development and out-of-school time programs with math and science learning**. The Youth Exploring Science (YES) program at St. Louis Science Center serves 250 teens each year,

[23] American Museum of Natural History (May 2009). "Emboldened Capacity: Science Education and the Infrastructure of Science-Rich Cultural Institutions." Prepared for the Carnegie-IAS Commission on Mathematics and Science Education. OpportunityEquation.org/go/amnh.

[24] Information on the New Tech High School model is available at Newtechhigh.org; cell.uindy.edu/NTHS/index.php.

[25] For descriptions of Seeds of Science/Roots of Reading and Concept-oriented Reading Instruction, including curricular materials, videos, and research reports, see seedsofscience.org. and cori.umd.edu.

[26] Duke's Engineering K-PhD Program is described at k-phd.duke.edu.

[27] For information on YES, see Youthexploringscience.com.

[28] Edumetrics (2007). *Summative Assessment of Kinetic City Omega/Sigma Afterschool*; see kcmtv.com/about.htm.

[29] Agile Mind is a commercial partner of the Charles A. Dana Center at the University of Texas at Austin; see utdanacenter.org. Uri Treisman, founder and director of the Charles A. Dana Center, is a member of the Carnegie-IAS Commission on Mathematics and Science Education.

[30] TeachScape is a commercial teacher development program, cofounded in 1999 by Roy Pea, director of the Stanford Center for Innovations in Learning; see teachscape.com.

[31] Wireless Generation, Inc., was cofounded by Commission member Larry Berger; see wgen.net.

[32] Commission member and science educator Katherine Ward serves on the faculty of the Exploratorium's summer teacher education institute.

[33] For the Meyerhoff Scholars Program, see umbc.edu/Meyerhoff/.

recruited through more than 20 community organizations, and engages them in inquiry-based learning in science, mathematics, and technology using a youth development approach.[27] Kinetic City, one of many out-of-school-time resources developed by the American Association for the Advancement of Science (AAAS), is an after-school "club" program developed with an interactive online component. Kinetic City has been shown not only to build students' science knowledge but to increase their ability to comprehend and write about complex text.[28]

- **Realizing the potential of cyberlearning through integrated math and science instructional programs.** Innovative programs developed by Agile Mind,[29] TeachScape,[30] and Wireless Generation[31] provide online teaching, assessment, and professional learning tools and have advanced thinking in the field about how face-to-face and online learning work most effectively together. These interactive programs are also finding new ways to draw on teachers' classroom experiences to refine curricular material and pedagogical approaches.

- **Building community assets into schools through intensive partnerships with math and science institutions**. "Science-rich" institutions like the American Museum of Natural History (AMNH), led by Commission member Ellen Futter, San Francisco's Exploratorium,[32] and the Museum of Science in Boston are leaders in a growing universe of museums that are developing new curricula and professional learning resources. Programs like these are giving hundreds of thousands of students and teachers access to museum collections and staff expertise—along with powerful insights into what people find most fascinating about science.

- **Supporting college success and advanced study by underrepresented minority students.** The Meyerhoff Scholars Program at the University of Maryland Baltimore County offers special supports to incoming students, mainly African-American, who aspire to careers in science and engineering. Students start with a summer program prior to freshman year featuring intensive credit-bearing courses in calculus and African-American studies and a range of noncredit courses. The program continues through graduation and includes academic advising and support in preparing graduate and professional school applications.[33]

- **Emphasizing the need for rigorous, relevant postsecondary learning as a basis for careers and civic life.** Princeton University recently redesigned introductory engineering courses to teach engineering as a liberal art to students preparing for careers in medicine, law, public policy, and visual arts. The revamped curriculum stresses design and analytic methods.

- **Coordinating resources from other sectors to raise math and science outcomes.** To increase the number of STEM students in higher education, especially those from minority and low-income backgrounds, the Rensselaer Polytechnic Institute is coordinating a "progressive dialogue" with leaders

Education entrepreneurs have altered the marketplace for teacher recruitment, data management, professional development, and other services, changing the way many school districts do business.

across New York State from business, government, education, and other sectors and developing a plan to coordinate their resources.[34]

A national mobilization would strengthen schools' ability to tap valuable resources and strategies, increase demand for further innovation, and allow the best approaches to be combined more strategically and implemented in more places. Examples of successful and promising programs are collected on the Commission's Web site at www.OpportunityEquation.org.

Excellent, equitable math and science education is a powerful, timely, and unifying goal, one toward which many individuals and institutions could contribute and where the potential payoffs are immense. Success would mean genuinely improved outcomes for a rising generation of American students and radically different elementary and secondary schools and institutions of higher education.

RECOMMENDED ACTIONS

The Commission recommends actions in two areas to build broad public understanding and commitment toward excellence and equity in math and science learning:

1. Mobilize the nation to improve math and science education for all students

By the federal government, states, school districts, and national and local education reform organizations

- Mount campaigns that generate public awareness of math and science as central to the revitalization of the American economy and social mobility for young Americans
- Increase public understanding that math and science are connected to a wide range of careers in many fields—virtually any secure and rewarding job in any sector of the economy
- Build understanding and will among policymakers and education, business, and civic leaders to close the gap between current education achievement and the future knowledge and skill needs of students

By colleges and universities

- Raise awareness and build support in colleges and universities for stronger and more coherent math and science preparation for all students
- Increase partnerships between higher education and K-12 systems to increase the number of students entering two- and four-year colleges well-prepared and able to take up mathematics and science learning

[34] To learn more about RPI's progressive dialogue on STEM education, see rpi.edu.

2. Place mathematics and science at the center of school improvement and accountability efforts

By the federal government, states, school districts, and national and local education reform organizations

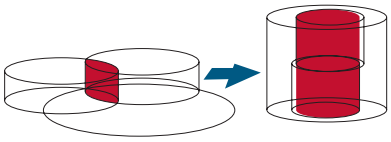
- Make improvement in math and science outcomes, especially by historically underperforming groups, a benchmark in designing and evaluating school improvement efforts at all grade levels for all students
- Incorporate math and science learning as part of the expected learning outcomes of initiatives in other areas, including literacy, social studies, art, and service learning

By businesses, nonprofit organizations, unions, philanthropy, and other partners

- Advocate for and support smart investments in K-16 mathematics and science achievement for a vital state, city, or regional economy
- Map assets in science and math, including science and technology-based industry, medical and health research and practice centers, and museums, and communicate how these can be leveraged for increasing math and science achievement
- Increase the science and math content in out-of-school time programming through project-based, real-world activities
- Incentivize the development of state, regional, and local science, math, engineering, and technology initiatives

A national mobilization would strengthen schools' ability to tap valuable resources and strategies, increase demand for further innovation, and allow the best approaches to be combined.

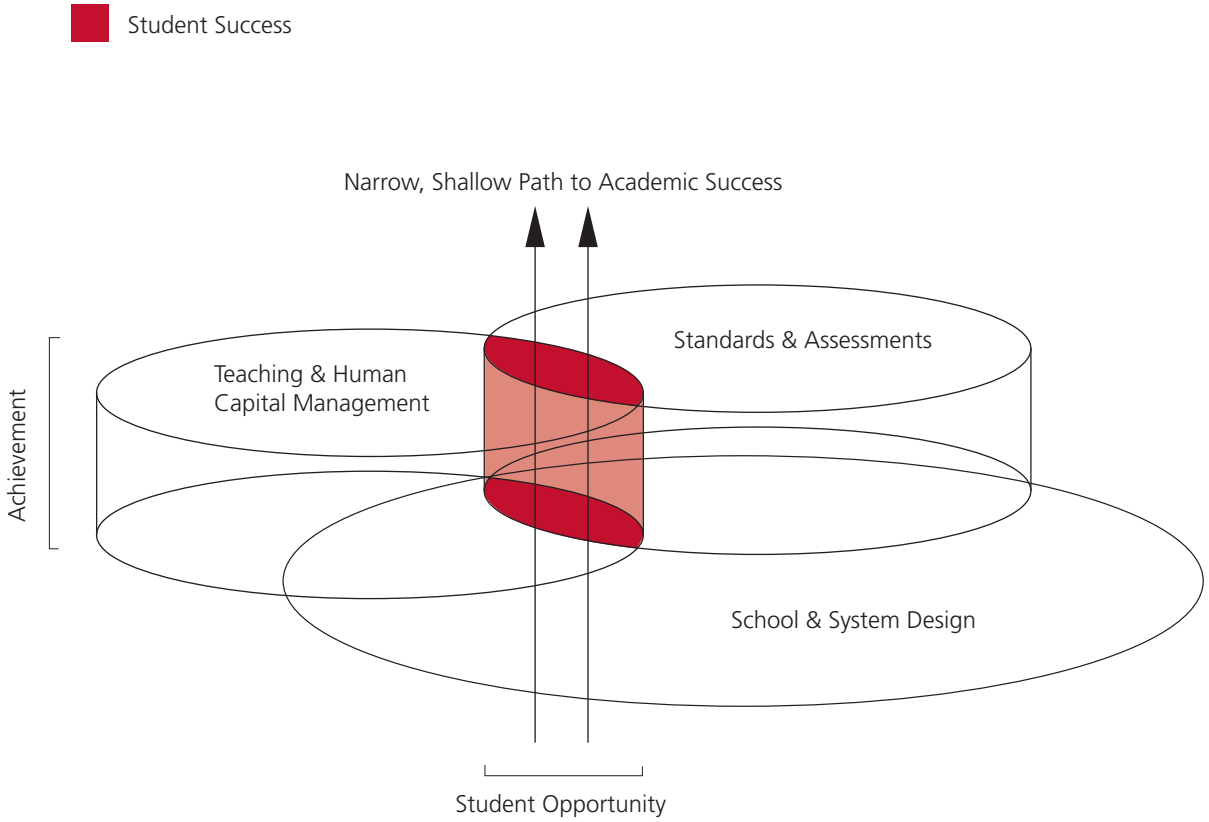
GOAL: A U.S. EDUCATIONAL SYSTEM ALIGNED FOR PERFORMANCE



The current educational system is seriously misaligned. Relatively few American students attend schools where all the major components—curriculum, teaching, and school design—line up to serve all students well. The Commission therefore urges coordinated action to bring the major components of our national educational infrastructure into alignment: standards and assessments, which guide schools in curriculum decisions; teaching, professional learning, and human capital management; and school and system design. An aligned system would give schools and districts the support they need to improve instruction, raise teacher performance, and implement new designs and innovations—thus providing many more students with opportunities for academic success.

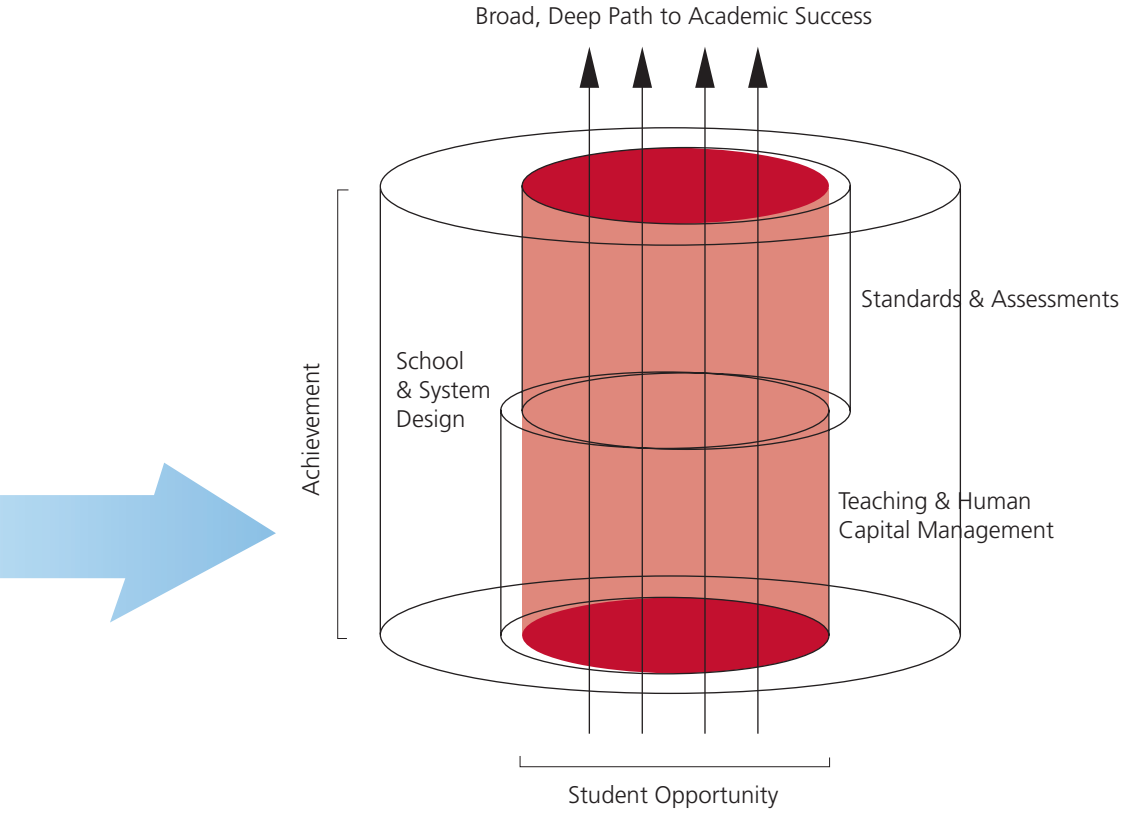
Misaligned Components of the Current U.S. Educational System

Poor alignment and development of resources results in low success and opportunity:
Too few students achieve, and overall level of achievement is low.



Aligned Components of a Transformed U.S. Educational System

By improving and aligning all aspects of the equation in concert, opportunity and achievement are improved.



[35] David Coleman and Jason Zimba (2007). "Math and Science Standards That Are Fewer, Clearer and Higher to Raise Achievement at All Levels." Prepared for the Carnegie-IAS Commission on Mathematics and Science Education. The Commission's thinking in this area has also been informed by the work of the Bill and Melinda Gates Foundation, whose leadership and support have enabled extensive investigation of standards and how they could be reshaped to foster school improvement more effectively.

[36] James B. Hunt, Jr., Testimony before the Committee on Education and Labor, U.S. House of Representatives. April 29, 2009. hunt-institute.org.

STANDARDS AND ASSESSMENTS: FOCUSING FOR ESSENTIAL KNOWLEDGE AND SKILLS

The time has come for the nation to adopt more academically rigorous common standards defining what mathematics and science education ought to look like for all Americans. The Commission believes that math and science standards should be fewer, clearer, and higher and that they should articulate our best understanding of what all students need to know and be able to do in order to succeed in college, thrive in the workforce, and participate in civic life. We endorse the proposition, advanced by David Coleman and Jason Zimba in a 2007 memorandum to the Commission, that "standards must be made significantly fewer in number, significantly clearer in their meaning and relevance for college and work, and significantly higher in terms of the expectations for mastery of what is covered."[35] In testimony to the House of Representatives in April 2009, Commission member James Hunt, former governor of North Carolina, argued that new, common standards "must be based on evidence of what's necessary and sufficient for students to succeed in college and in work. . . . It should be a tight common core that teachers can teach and students can understand and master."[36]

Further, we believe that, if common standards are to serve their intended purpose—to guide stronger math and science instruction for all American students and improve the performance of teachers, schools, and classrooms—they must be linked closely with new, high-quality assessments and more effective systems of accountability. The Commission also urges the adoption of guidelines for the periodic review and revision of standards and assessments to reflect new evidence about how students learn and what they need to know.

Common standards would be a strong platform upon which to build a more effective instructional infrastructure for American math and science education: educators, along with the schools, districts, and states in which they work, would be able to concentrate on *how* math and science are taught and on *how much* students are learning rather than on what to teach. Common standards would provide the framework for a widespread, national conversation about how educators can best help students in all groups—from struggling to advanced—to

master academically rigorous content and acquire essential skills. They would provide a similar framework for the preparation of future teachers.

Developed collaboratively by states for the nation but not federally promulgated or required, common standards would be national in scope and would provide a common frame of reference as states and school systems upgrade math and science education, rethink curriculum and course sequences, demand better textbooks and curriculum materials from vendors, and build math and science into students' learning across the curriculum. They would provide needed focus to teacher preparation and ongoing professional learning. For states that choose to adopt them, common standards would make tangible a set of thoughtfully considered, research-validated objectives for students, educators, and schools—objectives that could be refined over time as we learn from ongoing research on their implementation in different states.

High-quality common assessments, based on the proposed common standards and supporting their implementation, would encourage and reward effective instruction. Meaningful assessments that reward good teaching and learning would enable states and school systems to establish priorities, design instructional programs and approaches linked to the standards, and set long-range and interim targets for student and school performance. Assessments linked with common standards could be used in many states, thus opening the possibility of reducing costs and achieving more efficient processes for analyzing and improving the quality of the instruments. Common assessments would also enable states to assess the pace at which their schools are improving more effectively and to measure performance against international benchmarks.

OBJECTIVES

- Establish common mathematics and science standards that are fewer, clearer, and higher and that stimulate and guide instructional improvement in math and science and lead the way toward preparing all American students for a global economy
- Develop sophisticated assessments and accountability mechanisms that, along with common standards, stimulate and guide instructional improvement and innovation in mathematics and science

DISCUSSION

When the Commission began its work in 2007, the prospect of establishing core academic standards for the nation's school systems seemed like a distant prospect. The picture has changed dramatically over the past year, largely through the leadership of a few key organizations. In July 2008, Achieve, Inc., issued *Out of Many, One: Toward Rigorous Common Core Standards from the Ground Up*, which identified a "common core" of English and mathematics standards that 16 states

had already adopted voluntarily as college- and career-ready expectations for their high school graduates.[37] All 16 states, scattered across the country, are members of Achieve's American Diploma Project. This demonstration of a good level of agreement on key learning objectives among a diverse group of states suggests that finding common ground among most if not all states may well be achievable.

In September 2008, Achieve and two other groups—the National Governors Association (NGA) and the Council of Chief State School Officers (CCSSO)—joined forces to establish the International Benchmarking Advisory Group, an effort with the announced goal of ensuring that "American students in every state are receiving a world-class education." The advisory group issued a report, *Benchmarking for Success: Ensuring U.S. Students Receive a World-Class Education*, in December 2008, which "provides states a roadmap for benchmarking their K-12 education systems against those of top-performing nations.[38] Like *Out of Many, One*, the international benchmarking group report confined its recommendations to language arts and mathematics, but its call for higher expectations for all American students has clear implications for science.

Most recently, the NGA Center for Best Practices and CCSSO, in partnership with Achieve and other groups, have moved the country a major step closer to common standards with its Common Core Standards Initiative.[39] The development process has not yet been fully elaborated, but states have been offered a memorandum of understanding that spells out the principles of the work and guidelines for engagement. The goal is to release core high school standards in English-language arts and mathematics in late summer 2009 and develop grade-by-grade standards in those areas during the fall. Gene Wilhoit, a member of the Commission and executive director of CCSSO, signaled the group's intention to ensure the high quality of the work by assuring prospective state participants that "no state will see a decrease in the level of student expectations that exist in their current state standards."

Meanwhile, in both the mathematics and science education communities, there has been forward movement to find common ground and address the shortcomings of earlier efforts to create national standards.

Mathematics education has long been divided by contentious debates about curriculum and instruction. A breakthrough occurred with the 2005 Common Ground project, sponsored by the Mathematical Association of America, which brought together scholars and educators representing different orientations. They produced a set of understandings that all could agree to, demonstrating that there was less division than had previously been assumed.[40] The following year, the National Council of Teachers of Mathematics (NCTM) issued the *Focal Points* report, which spelled out a set of core ideas for mathematics in grades K-8. Prior NCTM standards had been criticized for not offering grade-by-grade guidance to teachers, a failing that allowed students to be taught the same subjects year after

[37] Achieve (2008). ***Out of Many, One: Toward Rigorous Common Core Standards from the Ground Up***. achieve.org/node/1018.

[38] International Benchmarking Advisory Group (2008). ***Benchmarking for Success: Ensuring U.S. Students Receive a World-class Education***. achieve.org/BenchmarkingforSuccess.

[39] For information on the Common Core Standards Initiative, including the principles included in the memorandum of agreement, see ccsso.org.

[40] Deborah Loewenberg Ball, Joan Ferrini-Mundy, Jeremy Kilpatrick, R. James Milgram, Wilfried Schmid, Richard Schaar (2009). ***Reaching for Common Ground in K-12 Mathematics Education***, The Mathematical Association of America.

[41] U.S. Department of Education (2008). ***Foundations for Success: The Final Report of the National Mathematics Advisory Panel***.

[42] President Barack Obama. Remarks to the Hispanic Chamber of Commerce on a Complete and Competitive American Education, March 10, 2009.

year. *Focal Points* provided that guidance and was well received by a wide range of mathematicians and mathematics educators. In 2008, the National Mathematics Advisory Panel, appointed by President Bush, embraced and embellished the central themes of the *Focal Points* work in its *Foundations for Success* report,[41] thus creating a foundation on which a full set of standards for grades K-12 might be constructed.

In science education, progress has been similar, although debates about curriculum and instruction have been less contentious—save for the special case of evolution. In 2007, the National Research Council issued *Taking Science to School*, which decried the "mile wide/inch deep" dilemma that plagues most states' science standards and curriculum. The report also acknowledged that the Academies had themselves contributed to the problem through their 1996 National Science Education Standards. The new study, looking exclusively at K-8 education, called for the development of new standards to focus instruction on core foundational ideas of science that all students need to learn. It also offered a new definition of science education that places greater emphasis on the practice of science and the importance of inquiry, not just memorization of key facts.

The Commission is heartened by these forward steps and urges widespread participation by states, educators, and the mathematics and science communities. The Obama administration has shown particular interest in promoting fewer, clearer, and higher standards for all students. As President Obama has asserted, "the solution to low test scores is not lowering standards—it's tougher, clearer standards."[42] If successful, the effort to establish common standards will provide an unprecedented basis for creating aligned systems of high-quality assessment that would guide effective instruction and strengthen the nation's ability to improve its schools.

Developed collaboratively by states for the nation but not federally promulgated or required, common standards would be national in scope and would provide a common frame of reference.

1. On establishing common math and science standards that are fewer, clearer, and higher

Common standards would enable states, and the country as a whole, to prioritize math and science learning and incorporate math- and science-related content, concepts, and processes into learning expectations for all grades and in all areas of the curriculum. Our lack of common standards and expectations makes it difficult to focus teacher education around essential knowledge and ideas that every student ought to gain command of and every teacher needs to know inside and out. It compromises the quality of textbooks and other resources by forcing publishers to aim for materials that cover too much at too superficial a level. But the ill-effects of a plethora of learning objectives cascade on, compromising teacher practice and state assessments as the push to cover required content makes it impossible for teachers to delve deeply into the most important content. The end result is American students deprived of the chance to develop scientific and quantitative reasoning skills, understand core concepts, see the relevance of math and science learning, or experience its excitement.

[43] U.S. Department of Education (2008). *Foundations for Success*: The Final Report of the National Mathematics Advisory Panel.

[44] National Research Council (2001). *Adding It Up: Helping Children Learn Mathematics*.

[45] Philip Daro (2008). "Mathematics for Whom: The Top of High School Meets the Bottom of College." Prepared for the Carnegie-IAS Commission on Mathematics and Science Education. OpportunityEquation.org/go/daro

Common standards, such as those being developed by the Common Core Standards Initiative, would address these shortcomings and enable educators and the educational system—nationally and in states and districts—to concentrate their efforts on creating and testing curricular materials, instructional strategies, and other resources that would serve the learning needs of the wide diversity of American students, from struggling to advanced learners, and enable deep learning. When complete, the standards will be available to all states on a voluntary basis.

There is also substantial agreement that mathematics and science standards must be fewer, clearer, and higher than those currently in use by states and recommended by national organizations. Standards that are fewer in number would reflect well-supported judgments within the field of what is essential for students to learn for future success in college and the workforce, the sequence in which they should learn it, at what depth, and over what period of time. Standards that are clearer would be well understood by educators and capable of being implemented coherently. Standards that are higher would guide the development and implementation of curriculum that is more academically rigorous and would result in many more students being prepared for higher levels of postsecondary education.

The *fewer*, *clearer*, *higher* criteria for developing standards for K-12 education could also serve as a framework for research and periodic review of the standards and their further refinement. In other words, the review process would look across states to determine whether or not the standards are promoting significant school improvement and meeting the instructional and implementation objectives of the fewer, clearer, higher framework. The experiences and resources of the country as a whole could be used to identify and address the strengths and weaknesses of existing standards, based on state, district, school, and student outcomes. With the right systems of review and research capacity, the United States would for the first time have a strong evidentiary basis for making major decisions about mathematics and science instruction and for periodically upgrading its K-12 academic standards.

In math, the Commission believes that instruction should emphasize inquiry, relevance, and a multilayered vision of proficiency such as the National Research Council spelled out in its important study of mathematics education, *Adding It Up* and carried forward by the National Mathematics Advisory Panel in its report *Foundations for Success*.[43] As articulated in *Adding It Up*, those proficiencies are:[44]

- Conceptual understanding (comprehension of mathematical concepts, operations, and relations)
- Procedural fluency (skills in carrying out procedures flexibly, fluently, and appropriately)
- Strategic competence (ability to formulate, represent, and solve mathematical problems)

- Adaptive reasoning (capacity for logical thought, reflection, explanation, and justification)
- Productive disposition (habitual inclination to see mathematics as sensible, useful, and worthwhile, coupled with a belief in diligence and one's own efficacy)

We also recommend careful consideration of the creation of a rigorous high school mathematics course sequence giving more attention to statistics, data analysis, and other discrete mathematics applications through secondary school and college. The standard high school math sequence of Algebra I, Geometry, and Algebra II as a precursor to Calculus has been urged upon states as a requirement for all students in recent years. There is little question that the traditional sequence provides a strong foundation for more advanced study for students interested in pursuing careers in science, math, or engineering, even while there is legitimate debate about the precise content of courses along the pathway. The Commission also believes, however, that an equally rigorous pathway, branching from the same core foundation as the calculus pathway, to include a thoughtfully reconfigured Algebra II course and subsequent courses through secondary school and college, might provide greater benefit to many American students.

There is substantial agreement that mathematics and science standards must be fewer, clearer, and higher than those currently in use.

As mathematics expert Philip Daro noted in his recommendations to the Commission, Singapore's highly regarded educational system "illustrates how it is possible to design multiple pathways to college entrance while still serving more specialized interests in the student population."[45] A statistics-oriented pathway through high school to college could be of real utility to students headed for careers in business, information technology, law and social science, and many other fields. Furthermore, additional study of statistics, probability, and data analysis would enhance the quantitative literacy students need for full participation in civic life. The widespread development of instruction in this area would also help introduce new content and pedagogy focused on problems that students might well find relevant and highly engaging.

The Commission recommends this change with the intention of strengthening the engagement of high school students in academically rigorous mathematics and encouraging them to pursue more mathematics at the college level. We are cognizant of concerns about educational equity: we emphasize that, in urging the development of this new approach, we are not recommending a return to dual-level, stratified math courses but the creation of two equally rigorous pathways to mathematics mastery. To ensure equity, the new courses would need to be developed in concert with a broadening of four-year college admissions requirements to recognize the new high school mathematics sequence.

Mathematician and educator Sol Garfunkel, in a paper prepared for the Commission, offers this reasoning: "As a mathematician, I recognize the beauty and centrality of calculus, but it should be more than clear by now that in terms of applications of mathematics in the work force, in daily life, for good citizenship and even for

success in further academic studies other branches of mathematics along with the processes of mathematical modeling are increasingly more relevant. Again this must be about the needs of students. We know that their future will involve many different jobs and the need to master current and emerging technologies. We know that they will need creativity, independence, imagination, and problem-solving abilities in addition to skills proficiency. In other words, students will increasingly need mathematical understanding and awareness of the tools mathematics provide in order to achieve their career goals." Drawing on experience in identifying skills needed in the workplace, Garfunkel proposes that students be offered rigorous "curricular alternatives—high school and college courses emphasizing discrete ideas taken from statistics, geometry, and operations research with case studies and applications to a variety of disciplines, work place settings as well as the kind of social decision making all of us will face."[46]

In science, the Commission recommends that standards be reshaped to counteract the tendency in American education to cover too much material in too little depth. The challenge is substantial in science: unlike in mathematics, science knowledge has proliferated enormously in the past 50 years and is likely to continue to do so. Our emphasis should therefore be on enabling students to develop the competencies that characterize scientific thinking and a more thorough understanding of the foundational concepts and theories that provide a baseline of scientific literacy and serve as building blocks for further studies.

Commission member, cell biologist and former president of the National Academy of Sciences Bruce Alberts emphasized in a recent editorial in *Science* magazine that "rather than learning how to think scientifically, students are generally being told about science and asked to remember facts."[47] Alberts assigns a portion of the blame to scientists themselves. After all, he contends, "college courses set the model for teaching science in the earlier years," and "any objective analysis of a typical introductory science course taught today in colleges and universities around the world . . . would probably conclude that its purpose is to prepare students to 'know, use, and interpret scientific explanations of the natural world' (strongly emphasizing the 'know'). This is but one of four goals recommended for science education" by the National Academies. From the earliest grades through college, all students need rich, educational experiences that enable them to develop the four strands of scientific proficiency identified in *Taking Science to School*:

- Know, use, and interpret scientific explanations of the natural world
- Generate and evaluate scientific evidence and explanations
- Understand the nature and development of scientific knowledge; and
- Participate productively in scientific practices and discourses.[48]

[46] Sol Garfunkel (2009). *Math to Work*. Prepared for the Carnegie-IAS Commission on Mathematics and Science Education. OpportunityEquation.org/go/garfunkel.

[47] Bruce Alberts (2009). "Redefining Science Education," *Science* 23. sciencemag.org.

[48] National Research Council (2007). *Taking Science to School: Learning and Teaching Science in Grades K-8*. Washington, DC: National Academies Press. P. 2.

[49] Jason Zimba (2009). "Five Areas of Core Science Knowledge." Prepared for the Carnegie-IAS Commission on Mathematics and Science Education. OpportunityEquation.org/go/zimba.

[50] Information about the Core Ideas meeting, along with commissioned papers, will be available through the Web site of the National Research Council's Board on Science Education at www.nationalacademies.org/bose/.

Rethinking science standards will depend, as well, on our ability to develop a more integrative way of organizing scientific knowledge than is currently available to most American teachers and students. Scientific research and advanced university education are moving decisively toward more interdisciplinary approaches. The Commission believes that the nation should embark on a broad-based conversation, led by and drawing on the expertise of our national scientific institutions, about the concepts, information, and areas of inquiry in which all students should develop foundational knowledge—and from which many students will proceed to much higher levels of learning.

As a starting point for that conversation, the Commission offers as an example a taxonomy of "core science knowledge" proposed by physicist and educator Jason Zimba.[49] Zimba offers five major categories, each vividly relevant to the daily lives of students of all ages, able to accommodate a wealth of topics, and cutting across the standard scientific disciplines:

- Where we are in the universe
- How we came to be
- The organizing principles of contemporary science
- Human health and well-being
- What science and technology can do today

Our emphasis should be on enabling students to develop the competencies that characterize scientific thinking and a more thorough understanding of foundational concepts and theories.

The National Research Council, through its Board on Science Education, will convene a meeting during the summer of 2009 as a critical first step toward a process to revise the National Science Education Standards. This planning meeting, sponsored by the National Science Foundation, will focus on core disciplinary ideas in K-12 science education. As preparation for the meeting, the Board on Science Education will commission papers that will synthesize key issues around what constitutes a core disciplinary idea from the vantage points of the science disciplines and the learning sciences.[50] Further discussion by the Board on Science Education on the process for undertaking identification of core disciplinary ideas, and the relationship of this work to the possible revision of the National Science Education Standards, will follow this initial planning meeting.

The Commission applauds this step and encourages the National Research Council and other parties to take advantage of the momentum gained through the recent work of the Common Core Standards Initiative toward developing common standards in mathematics and English language arts.

2. On developing sophisticated assessments and accountability mechanisms

The development of new, high-quality classroom assessments and accountability mechanisms, linked to common standards, is an important priority—indeed, a

necessity if common standards are to achieve their maximum effect for improving math and science education for all American students. Assessments aligned with common standards will also be essential to the creation of useful, accurate measurements of teacher, school, district, and state performance.

As Stanford University professor and assessment expert Edward Haertel wrote in a paper presented to the Commission, "assessment is woven into the fabric of educational practice in the United States. Individual assessments help determine the classifications of students as gifted, learning disabled, English Learners, or ADHD. The quizzes, unit tests, and final exams that teachers create or choose help determine the pacing of classroom instruction, instructional grouping, and marks and grades, as well as informing students about expectations for learning and about their success in meeting those expectations. Advanced Placement and International Baccalaureate tests define ambitious curricula for respected high school courses. The SAT and the ACT are central to the sorting and selecting process at the point of college admissions. High school exit examinations are viewed as a form of quality assurance, but also stand as significant barriers to graduation for substantial numbers of students. State testing systems mandated under the No Child Left Behind Act of 2001 (NCLB) define school-level success or failure, and a range of sanctions are imposed if scores repeatedly fall short of targeted levels."[51]

Of these, the most important for raising mathematics and science achievement for all American students are classroom assessments and assessments for accountability. If well crafted and administered appropriately, classroom assessments can provide information about student learning and help teachers improve instruction. If well aligned with standards or other clear statements of expectation, assessments for accountability can provide information about how students, teachers, schools, or even states and nations are performing and whether or not students are learning prescribed curriculum; that information, in turn, can help shape improvements to instruction and to educational practice and policy. Experience has shown that it is not easy to get assessments right: assessments are frequently used for purposes they were not designed for, and rote preparation for "high-stakes" tests displaces or distorts other learning goals. In science, for example, the need to obtain reliable results from tests that are easy and inexpensive to administer has driven assessments—and instruction—toward the first strand described in *Taking Science to School* ("know, use, and interpret scientific explanations of the natural world") and away from the other three more complex and difficult-to-assess competencies.

The Commission believes that better assessments will be crucial to guide and reinforce improvements to mathematics and science instruction in American schools and colleges, and that those assessments should be closely linked to the new fewer, clearer, and higher standards. In addition, as Haertel has argued, it will be essential to improve and clarify "the rules by which [assessments] are used or interpreted," which may require "decoupling the multiple purposes for which some tests are used" and making appropriate changes in federally mandated accountability systems. Following Haertel's

[51] Edward Haertel (2009). "Reflections on Educational Testing: Problems and Opportunities." Prepared for the Carnegie-IAS Commission on Mathematics and Science Education. For a review of high school models focusing on 21st century skills, including a case study of New Tech High School, see Elena Silva (2008), ***Measuring Skills for the 21st Century***, Education Sector.

recommendations, the Commission therefore urges development and implementation of five interconnected types of classroom-level and accountability assessment:

- Portfolio-based school accountability, which should incorporate student- or classroom-level math and science portfolios
- Performance assessment component for school accountability, which should include matrix-sampled school-level performance assessments
- Classroom assessment for learning, using improved curriculum-embedded formative assessments
- Better high-stakes tests that are closely linked to new mathematics and science standards
- Better decision rules for evaluating school-level assessment results

Developing these systems and putting them into place would need to be phased with care, with supports provided to districts, schools, teachers, and parents and communities about what each component is intended to measure and how it operates.

The development of new, high-quality classroom assessments and accountability mechanisms, linked to common standards, is a necessity if standards are to achieve their maximum effect.

The Commission also believes that new assessments should be informed by and calibrated against the most reliable international measurement systems in mathematics and science—the Programme for International Student Assessment (PISA), which periodically assesses the skills and knowledge of 15 year olds in mathematics, science, reading, and problem solving and measures changes in student performance, and Trends in International Mathematics and Science Study (TIMSS), which periodically measures the performance of fourth and eighth graders—and the skills and knowledge those systems assess. Wider use of internationally benchmarked assessments would give states and the federal government a more meaningful picture of student and school performance and would inform district and state efforts to improve American schools. The science framework for the 2009 National Assessment of Educational Progress also lays out a well-regarded, comprehensive approach to assessing content knowledge, its application, and students' command of the process and practice of science for students in grades 4, 8, and 12. The new NAEP framework should inform the development of new common state and classroom assessments.

A number of groups are deeply engaged in developing college-ready assessments, which are designed to help increase students' academic readiness for college by articulating college expectations clearly and enabling schools to develop student competencies accordingly. For example, as part of making college readiness a nationwide goal, the American College Testing organization (also known as ACT), developed its College Readiness Standards for the middle school and high school grades, drawing on extensive knowledge of what students are likely to need to know and be able to do gained through administering its widely used, integrated

[52] Brian Rowan (2007). "Changing Instruction and Improving Student Learning: Lessons from Comprehensive School Reform." Prepared for the Carnegie-IAS Commission on Mathematics and Science Education. OpportunityEquation.org/go/rowan. For information on Quality Core, see act.org/qualitycore.

[53] National Research Council (2002). *Learning and Understanding: Improving Advanced Study of Mathematics and Science in U.S. High Schools*.

series of assessments and career planning programs (including the EXPLORE assessment for grades 8 and 9, PLAN for grade 10, and the ACT assessment for grades 11 and 12). More recently, ACT also launched its Quality Core end-of-course assessments in English, math, and science, which are designed to support college-ready high school curricula and are accompanied by course syllabi, suggested sequencing guidelines, model instructional units, and professional development; together, they create an aligned instructional approach that research suggests has real potential to lift student performance.[52] The College Board is currently in the midst of redesigning its Advanced Placement courses and exams in biology, chemistry, and physics, based largely on recommendations by the National Academies in 2002.[53] The new exams should accelerate improvements in classroom practice in both high schools and colleges.

While assessing students' college readiness skills, it is critical that stronger links be made between assessments, professional development, and classroom practice. The Educational Policy Improvement Center (EPIC) in Eugene, Oregon, for example, is working with more than 40 Urban Assembly public schools and California Early College High Schools to develop the College-Readiness Performance Assessment System (C-PAS), designed to gauge student progress in grades 6–12. C-PAS is a series of classroom assignments (or performance tasks) that teachers incorporate into class work and score with a common scoring guide. Teachers can use the results to consider how well their curriculum is helping students to reason, solve problems, interpret information, conduct research, and generate work with precision and accuracy. Assignments, or tasks, encourage students' development in these key cognitive strategies over time. The goal of the project is to create formative assessment systems that teachers, schools, and school districts can employ to help ensure students are ready for college.

The Commission also encourages the development of more sophisticated formative assessments for classroom use, along with systems by which teachers can access proven assessments, share techniques and instruments, and collaborate in refining them. At its best, a formative assessment delineates and measures a student's progress not only against a rigorous standard in totality but against component skills as they fit together. A good assessment, by illuminating the broad spectrum of skills required for mathematics or science success, can inform instruction by revealing strengths and gaps in a student's understanding and enabling a skilled teacher to calibrate the needed instructional response. Sophisticated, multilayered, and rigorous assessments are the essential counterpart to fewer, clearer, higher common standards, as the former drives accountability and practice in alignment with the latter.

RECOMMENDED ACTIONS

The Commission recommends actions in two areas toward focusing on essential mathematics and science knowledge and skills:

1. Establish common math and science standards that are fewer, clearer, and higher and that stimulate and guide instructional improvement and galvanize the nation to pursue meaningful math and science learning for all Americans

By the federal government

- Endorse the National Governors Association and CCSSO Common Core Standards Initiative process and the creation of common, national standards that are fewer, clearer, and higher in mathematics and English language arts; urge the Common Core states to tackle science standards in the next round of development
- Support research and development activities that strengthen our collective understanding of what all students need to know and be able to do in order to succeed in college, thrive in the workforce, and participate in civic life
- Take steps to increase public understanding of the connection between better standards and better math and science education for all students

By governors and states

- Participate in the Common Core Standards Initiative to develop fewer, clearer, and higher common standards in mathematics and English language arts
- Within the Common Core Standards Initiative, encourage the development of science standards in the next round of development, utilizing the four strands of scientific proficiency and demonstrated capacities in the work of science identified in the report of the National Research Council, *Taking Science to School* (2007)
- Work with other states and with K-12 and higher education system leaders to explore the feasibility of offering a mathematics pathway to college for secondary students that is equally rigorous to the calculus pathway and that features deeper study of statistics, data analysis, and related discrete mathematics applications, beginning with a redesigned Algebra II course; write standards to enable that pathway and ensure rigorous learning
- Make a public commitment to mathematics and science standards that are fewer, clearer, and higher—and based on the best existing evidence about the developmental trajectory of how students learn and the skills and knowledge they need for further education, work, and citizenship
- Learn more about the standards development efforts of states that have made recent progress, such as Indiana, Minnesota, and Massachusetts, and apply lessons from that work to improve practice and build greater consensus
- Join with other states in a continuous process of improving mathematics and science standards, based on a growing evidence base about student learning, needed skills and knowledge, and the efficacy of existing standards
- Take steps to increase public understanding of the connection between better standards and better math and science curriculum and instruction for all students

Wider use of internationally benchmarked assessments would give states and the federal government a more meaningful picture of student and school performance.

- In science, become familiar with the work beginning at the National Research Council in July 2009 to develop a process for identifying core disciplinary ideas in science and transfer lessons learned from this process to the development of a Common Core in science
- Support efforts toward developing standards that encourage greater integration of literacy development within mathematics and science and a stronger emphasis on the cognitive and developmental research that can inform math and science learning across the curriculum in both K-12 and higher education

By colleges and universities

- Work with K-12 systems to redefine rigorous mathematics pathways that include data analysis and statistics and lead to admission to four-year colleges
- Redesign introductory and required courses in mathematics and science to connect more seamlessly with new secondary standards by providing rigorous development of quantitative and scientific literacy skills needed by all students for further education, work, and citizenship
- Assess the quality and levels of learning in mathematics and science by undergraduate students, especially during the first two years of college
- Review science and math curriculum with an eye toward increasing undergraduate competence in using and interpreting scientific evidence and participating in scientific practices and discourse

By businesses, unions, nonprofit organizations, and other partners

- Support state involvement in Common Core Standards Initiative and promote the development of high-quality standards in mathematics and science
- Engage teachers and school leaders in promoting fewer, clearer, and higher standards in math and science in their states as essential to their ability to strengthen instructional practice

By philanthropy

- Support state efforts to participate in the Common Core Standards Initiative and other efforts to develop fewer, clearer, and higher standards
- Fund research that strengthens the evidence base regarding what students need to know for further education, work, and citizenship and how teachers and schools can best support student learning
- Support research and the development of new practices in mathematics and science learning that would inform standards that are fewer, clearer, and higher and support the infusion of math and science learning across the curriculum

2. Develop sophisticated assessments and accountability mechanisms that, along with common standards, stimulate and guide instructional improvement and innovation in mathematics and science

By the federal government

- Incentivize development of higher quality assessments in mathematics and science for use by states and districts to evaluate teaching and learning and guide instructional improvement
- Fund research on the effects of new standards and assessments on student performance and on instruction

By governors and states

- Use the newly designed fewer, clearer, and higher standards as a foundation for developing assessment systems that inform instructional improvement, support curricular innovation, and give students, parents, and communities better information about school performance and student progress
- Work with other states to create national systems of assessment, data gathering, and data reporting and to create common validation frameworks for assessing the quality and effectiveness of state standards and to inform their periodic revision

By businesses, unions, nonprofit organizations, and other partners

- Endorse the development of new assessment and data systems to strengthen knowledge about student learning and provide a stronger foundation for continuous school improvement and innovation
- Engage in research and implementation of alternative assessments that better support the four strands of science learning identified in *Taking Science to School*

By philanthropy

- Fund research and development efforts to create new assessment systems that measure the performance of students, teachers, schools, and states in meeting new standards and generate information to inform the continuous upgrading of those standards
- Fund research on the effects of new standards and assessments on student performance and on instruction

Sophisticated, multilayered, and rigorous assessments are the essential counterpart to fewer, clearer, higher common standards.

[54] Allan Odden and James A. Kelly (2008). "Strategic Management of Human Capital in Public Education," Consortium for Policy Research in Education, P. 2.

[55] Business-Higher Education Forum (2008). "The Case for Predictive Methods in STEM Education Research & Policy Analysis." Draft concept paper for the STEM Research and Modeling Network. bhef.com/solutions/documents/srmn_concept.pdf.

TEACHING AND PROFESSIONAL LEARNING: MANAGING FOR EFFECTIVENESS

Education is a people business that relies first of all on the talent, skill, and commitment of teachers and school system leaders. For students, no school factor is more important to learning than the quality of their teachers. As the primary asset of the American educational system, our nation's educators deserve savvy, strategic management. The tasks involved are many: school systems need to recruit and develop qualified candidates for teaching and leadership roles, place them intelligently and equitably in the right positions, cultivate their skills and sustain their commitment over time, and monitor and manage their performance with relevant metrics.[54] For a system dedicated to increasing student achievement in math and science, the incentive to manage well is especially great, since those areas have historically been among the most difficult to staff with highly qualified educators.

Many school districts are seeking to improve their human capital management systems, often experimenting with performance management techniques borrowed from the private sector and getting assistance with specific functions from external organizations. Meanwhile, national groups such as the Business-Higher Education Forum have stepped up research on the "pipeline" of math and science teachers and other human capital questions, using systems dynamics modeling and other techniques.[55] Promising human capital management practices could improve working conditions and help retain highly qualified mathematics and science teachers, yet they have not yet reached enough schools. In the next few years, as the nation seeks sustainable solutions to the current economic crisis, we have an unprecedented chance to look rigorously at the human capital demands of the education sector—the sector on which all other workforce investments depend.

The Commission urges the nation and its school systems to rethink and reorient human capital management with the explicit goal of maximizing math and science learning. The Commission believes that progress, and ultimately success, should be judged in terms of meaningful student learning, teacher effectiveness and improvement, and the ability of schools to innovate and adapt to meet the future needs of society.

OBJECTIVES

- Increase the supply of well-prepared teachers of mathematics and science at all grade levels by improving teacher preparation and recruitment
- Improve professional learning for all teachers, with an eye toward revolutionizing math and science teaching
- Upgrade human capital management throughout U.S. schools and school systems toward ensuring an effective teacher for every student, regardless of socio-economic background

DISCUSSION

To achieve dramatic improvements in math and science education for all students, we will need to increase the supply of teachers with strong working knowledge of mathematics and science and the pedagogical techniques necessary to teach math and science effectively. Our secondary schools will continue to need math and science teachers with deep, specialized knowledge of those disciplines, and increasing their numbers must continue to be an important priority. For the future, however, we must also aim to build a teaching profession in which *all* teachers, in every discipline and from the elementary grades on up, are "STEM-capable," or sufficiently conversant with math and science content and relevance to infuse their classrooms with rigorous, motivating math and science learning. To prepare American students to participate fully in tomorrow's economy and society, our K-14 educational system needs a STEM-capable human capital infrastructure.

The question, then, is partly one of numbers. We will need to attract many well-prepared candidates to the teaching profession, expand successful teacher recruitment programs, and provide teachers with more effective support and guidance during their first years in the classroom. We must also do more to retain effective teachers, improve their working conditions, and deploy them skillfully to improve our schools.

But numbers alone will not solve the problem: schools and districts need to manage human capital as part of an educational improvement strategy that takes seriously the practical challenges of educating *all* students to higher levels of proficiency. We need teachers who are knowledgeable, motivating, inspiring—and able to differentiate instruction to enable every student to achieve higher levels of math and science learning. This will require ensuring that teachers and school leaders know what excellent teaching looks like and have the necessary tools, skills, and opportunities to meet students' diverse learning needs.

As a foundation for all this, undergraduate institutions will need to upgrade the math and science education every aspiring teacher receives, including those who do not intend to teach secondary math and science. Indeed, math and science learning is a crucial priority for all undergraduates: they are tomorrow's teachers, parents, and leaders, and math and science will be increasingly important in all those roles.

Further, to realize the full value of changes such as these, human capital management systems must be strengthened in our schools, districts, and states. As one recent analysis showed, "job dissatisfaction" is cited most often by teachers as their main reason for leaving their jobs—leading co-investigator Richard M. Ingersoll to liken efforts to increase the supply of math and science teachers to "pouring water in a leaky bucket" until teachers' working conditions are improved.[56] A more dynamic, innovative, and professional teaching force will require better leadership and management of schools and systems, deeper engagement in instructional improvement and accountability, more meaningful assessment of teaching effectiveness, and expanded roles for exemplary teachers. Educators, individually and as a profession, will need to be afforded greater recognition and respect.

1. On increasing the supply of well-prepared teachers of mathematics and science at all grade levels by improving teacher preparation and recruitment

Teacher certification is the mechanism states use to ensure that their schools are staffed by qualified professionals. Most teacher candidates obtain their initial certification by completing a college- or university-based program that combines academic coursework and supervised clinical experiences, or student teaching. Some candidates, especially those who intend to teach elementary grades, satisfy initial certification requirements during their undergraduate years and go directly from college into teaching. Others, especially those who aim for the more specialized certifications needed for secondary school teaching, enroll in post-baccalaureate, or "5th year," programs; there, aspiring teachers who already have a bachelor's degree in a particular discipline gain academic and practical experience in education—and the credential they need to take up a teaching position.

These two routes produce a steady supply of teachers; they do not, however, produce enough math and science teachers to meet today's needs. The problem is especially acute in some regions of the country and difficult-to-staff schools and districts.[57]

And it's no wonder. Conventional undergraduate and post-baccalaureate programs have limited appeal to math and science majors and graduates, who typically have a multitude of career choices open to them—many in fields more lucrative than education. Moreover, universities are not accountable for meeting the need for math and science teachers and have historically given little attention to teacher recruitment, generally preferring to serve any qualified student who chooses to enter a program rather than recruit students whose interests and academic backgrounds match school district needs. School districts with particular recruitment challenges—for secondary math and science teachers, for example, or for teachers willing to work in difficult-to-staff urban schools—have developed their own tactics to fill those gaps, such as recruiting certified teachers from other locales (sometimes even from abroad) or establishing temporary certification programs.

[56] Debra Viadero (2009). "Educator Loss in STEM Area Called Issue: Overall Shortage Disputed," *Education Week*. edweek.org/ Richard M. Ingersoll and David Perla (2009). "The Mathematics and Science Teacher Shortage: Fact and Myth," CPRE Research Report #RR-62.

[57] Math and science were teacher shortage areas in 47 states in 2007-08. "Teacher Shortage Areas Nationwide Listing 1990-1991 through 2009-2010," U.S. Department of Education, Office of Postsecondary Education (2009). ed.gov/about/offices/list/ope/pol/tsa.html.

[58] For example, according to the New Teacher Project's internal data, 83 percent of its 2008 fellows were teaching in the high-needs subject areas of science, math, and special education. Presentation to the Carnegie Corporation of New York, February 2009.

[59] Donald Boyd et al. (2008). "The Narrowing Gap in New York City Teacher Qualifications and Its Implications for Student Achievement in High-Poverty Schools," NBER working paper. (Note: A co-author of this study, Susanna Loeb, is a member of the Carnegie-IAS Commission.) In 2008, a Louisiana Board of Regents report showed that the New Teacher Project's first-year math teachers had a more positive effect on students than traditionally certified teachers who had taught for 2+ years. Similarly, a 2008 Urban Institute study showed that high-school students taught by TFA corps members performed significantly better on state-required end-of-course exams, especially in math and science, than peers taught by far more experienced instructors. Louisiana TNTP report: regents.state.la.us.

[60] See, for example, the qualifications for the math and science immersion programs of the New York Teaching Fellows Program at nyctf.org/prospective/fellowship.html.

In recent years, organizations such as The New Teacher Project (TNTP) and Teach for America have attempted to fill the recruitment gap by offering alternative routes into teaching for candidates who lack traditional teacher preparation, often appealing directly to candidates' desire to do something worthwhile for children and society. Working in partnership with school systems in cities such as New York City, Chicago, and Baltimore, these independent, nonprofit programs have expanded the pipeline of teachers who are willing, even eager, to work in difficult-to-staff urban schools, often in shortage areas such as math and science.[58] The programs recruit nationally and are highly selective. In general, teachers recruited via these alternative routes have higher observable academic qualifications than the supply of teacher candidates that districts attract, and their deployment in high-poverty schools appears to have contributed to higher student achievement, especially in math and science.[59]

The best alternative certification programs hold considerable promise for the nation, especially in math and science.

Yet even alternative-route programs are sometimes forced to make special efforts to attract math and science majors. Math for America, a growing nonprofit that places its fellows in schools in New York City, San Diego, Washington, DC, and Los Angeles, requires "strong quantitative preparation" but not necessarily an undergraduate major in mathematics. The New York City Teaching Fellows Program—a district-sponsored initiative, described below—has taken the step of adding enhanced math and science immersion strands to its general program, each aimed at attracting and preparing candidates who did not major in science or math during college but have some math and science background and are interested in teaching in those fields.

The alternative certification field has grown dramatically in recent years, and evidence suggests that, similar to variations across other teacher entry routes, there is variation in the quality of programs. Yet the best alternative certification programs hold considerable promise for the nation, especially in mathematics and science, as well as lessons about what it takes to bring well-educated, talented, but uncertified candidates into teaching and to support them through the transitional "induction" period. Some districts are now applying those lessons in programs of their own design, often relying on philanthropic support to shape and pilot their initiatives and tailoring the components to suit local circumstances.[60] The Boston Teacher Residency, for example, trains approximately 75 fellows per year in an intensive program managed jointly by the school district and an intermediary organization, the Boston Plan for Excellence. The program offers teacher candidates a 13-month, clinically based alternative pathway to teacher certification; components include a full-year internship in a Boston school, during which the fellow works closely with a mentor teacher; summer sessions before and after the residency year; a stipend for living expenses; and a forgivable loan toward a master's degree. By contrast, the New York City Teaching Fellows Program is larger, enrolling roughly 1,600 candidates per year. It aims to attract both career changers and new college graduates with strong academic background by placing fellows in full-time, fully paid teaching positions in their first year and providing them with an intensive pre-service summer institute, mentoring by an experienced teacher, and enrollment in a subsidized master's degree program in education through a local university.

Some colleges and universities are using similar design elements to create unconventional teacher preparation programs aimed at undergraduate math and science majors—students unlikely to enroll in standard teacher preparation programs and attracted to the intellectual rigor and challenge of mathematics and science. At the University of Texas at Austin, for example, the UTeach Natural Sciences program was established by the dean of the College of Natural Sciences, who forged partnerships with the university's College of Education and College of Liberal Arts and with the Austin Independent School District. UTeach vigorously recruits math and science majors to become teachers, offering them intensive clinical preparation for the challenges of secondary school teaching in science, math, computer science, and engineering. Students may enter UTeach at multiple points in their undergraduate schooling and are usually able to complete the requirements for certification by the time they graduate. UTeach also offers post-baccalaureate programs in math and science education for college graduates and already certified teachers. The program has an ambitious replication agenda, and versions of the model are now operating in 13 universities around the country.[61]

Collectively, innovative programs such as these are beginning to push other teacher preparation programs to reconsider the way they work and their lack of connection with school system needs. Commission member Susanna Loeb and Pam Grossman have argued that the rapid growth of alternative-route programs has "demonstrated the need for institutions that prepare teachers to be more responsive to the immediate needs of school districts. Alternative routes developed, in large part, because existing institutions could not respond quickly enough to projected and actual teacher shortages, especially in high-need areas."[62]

Within the bounds of more conventional teacher preparation, some colleges and universities are beginning to link their programming with school system needs in mathematics and science. For example, the University of Washington has established two post-baccalaureate fellowship programs—the Noyce Fellowship and the Lenore Annenberg Teaching Fellowship—which offer aspiring math and science teachers a year of academic and clinical preparation, followed by mentoring and support during their first years of teaching in high-needs local schools. The Institute for Science and Mathematics Education, a research center within the university's College of Education, operates several projects that involve teacher candidates, K-12 practitioners, and faculty members (in education, and also in science and mathematics) in studying the development of teacher skill and other research questions.

In another example, the Long Beach, California, school district has become deeply involved in shaping the credentialing programs at California State University Long Beach. The district's curriculum specialists teach in CSU's program and have helped to develop a program in which coursework and clinical experience are well integrated. The Long Beach district also offers early employment contracts to prospective science and math teachers prepared through the CSU program.

[61] UTeach Natural Sciences was honored in 2009 by Harvard's Ash Institute for Democratic Governance and Innovation as one of the Top 50 Innovations in American Government. http://ashinstitute.harvard.edu/.

[62] Susanna Loeb and Pam Grossman (2008). *Alternative Routes to Teaching: Mapping the New Landscape of Teacher Education*, Harvard Education Press.

[63] John Dossey, Katherine Halvorsen, and Sharon McCrone (2008). "Mathematics Education in the United States 2008: A Capsule Summary Fact Book." National Council of Teachers of Mathematics.

[64] Conference Board of the Mathematical Sciences (2001). *The Mathematical Education of Teachers*.

[65] John Dossey, Katherine Halvorsen, and Sharon McCrone (2008). *Mathematics Education in the United States 2008: A Capsule Summary Fact Book*. National Council of Teachers of Mathematics, P. 54.

[66] Julie Greenberg and Kate Walsh (2008). *No Common Denominator: The Preparation of Elementary Teachers in Mathematics by America's Education Schools*, National Council on Teacher Quality.

The quality of teacher preparation is an issue, but so is the role of math and science courses in undergraduate education generally, and especially for teacher candidates. Undergraduates who plan to become elementary school teachers and who are not majoring in science, mathematics, or engineering tend to study very little math or science, with few or no courses required beyond an institution's general education requirements.[63] Overall mathematics preparation of elementary school teachers falls below goals outlined in 2001 by the Conference Board of the Mathematical Sciences (CBMS), which recommends at least nine semester hours, equivalent to three courses, of undergraduate study.[64] Scant preparation puts elementary school teachers and their students at a severe disadvantage, given the importance of math achievement in state accountability systems. For the middle grades, CBMS recommends that mathematics be taught by specialists with at least 21 semester hours in mathematics, including at least 12 semester hours on fundamental ideas of mathematics appropriate for middle grades students. At least one-third of the nation's eighth graders are being taught by teachers who have not met these advisory goals.[65]

According to a 2008 study by the National Council on Teacher Quality (NCTQ), few colleges are giving attention to this issue—although change is possible. One teacher preparation program, at the University of Georgia at Athens, requires very substantial mathematics preparation for aspiring elementary grades math teachers: five semesters, three in math content, taught within the university's mathematics department, and two in math teaching methods, taught within the school of education.[66] Named an "exemplary program" in the NCTQ report, it may well point the way for other programs. But raising standards in these ways is likely to be effective only if higher education raises standards for all undergraduate learning in mathematics and science. The core preparation in math and science needed by teachers is also needed for a wide range of professions in the new economy. The pool of students who are academically well-prepared in math and science from which teacher candidates can be recruited must be expanded. In addition, further research is needed on the impact on pupil achievement of the math and science preparation of their teachers.

2. On improving professional learning for all teachers, with an eye toward revolutionizing math and science teaching

To lead a revolution in math and science education, teachers themselves need opportunities to experience powerful math and science learning. Motivating, relevant, inquiry-based science and math learning—the type of learning that teachers and teacher candidates might not have received in their own earlier education but will be called upon to offer to their students—should be built into teachers' initial preparation and ongoing professional development. Educators also need continuous contact with fresh content, especially in science and technology, where knowledge has grown rapidly in recent decades and fast-paced innovation will continue to open new opportunities for learning.

To lead a revolution in math and science education, teachers themselves need opportunities to experience powerful math and science learning

[67] For more information on Urban Advantage, see urbanadvantagenyc.org/home.aspx.

[68] For more information on Engineering for the Future, see mos.org/etf/.

[69] Michael Barber, Mona Mourshed, and Fenton Whelan (2007). "Improving Education in the Gulf," *McKinsey Quarterly*, P. 44.

[70] Data on the performance of New Leaders principals are available at nlns.org/Results.jsp.

[71] Liz Gewirtzman (2008). "An Unorthodox but Pragmatic Approach to National Math and Science Literacy." Prepared for the Carnegie-IAS Commission on Mathematics and Science Education.

[72] newvisions.org/dls/AnnualReport 2007.pdf

Museums and other "science rich institutions" are emerging as important sources of in-depth, up-to-date learning for teachers in science, math, and related disciplines. The Exploratorium in San Francisco, for example, offers an intensive summer institute to secondary school science teachers, during which participants conduct experiments and test curricular units that they later implement in their classrooms. In a notable trend, several leading science institutions have begun to redefine their own roles to assume more responsibility for student learning—a change that strengthens their institutional commitment to increasing teachers' knowledge. The Urban Advantage program, developed by the American Museum of Natural History (AMNH) in collaboration with the New York City Department of Education and other local institutions, shares responsibility for enabling 20,000 New York City eighth graders to complete their state-mandated science "exit projects" and provides participating teachers with 50 hours of professional development.[67] AMNH also offers online credit-bearing courses taught by its scientist faculty. The Museum of Science in Boston offers a broad menu of professional learning opportunities for teachers, including workshops, institutes, online courses linked with science and engineering curricula, and collaborations with area biotech firms. Recently, the Museum developed an introductory, year-long engineering course for students in grades 9-12, Engineering the Future, along with an in-depth program of teacher support.[68]

Teachers need ready access to the best and most motivating materials, but they also need better mechanisms for sharing teacher-tested math and science resources. The division between *professional learning* about math and science and *teaching* math and science needs to be diminished, if not erased. A coherent approach to professional learning—for both teacher candidates and practicing teachers—would enable educators to contribute to a common store of curricular and pedagogical materials that support student progress toward meeting new, higher common standards.

Professional learning in science and math could be organized around using, customizing, and perfecting a set of well-documented lessons and pedagogical approaches. In math especially, such an approach could draw on the Lesson Study method, used widely in Japan and increasingly internationally. Schools using programs like Agile Mind, led by Commission member Uri Treisman, are already demonstrating practice in this area. Delivered to schools and districts as a blended professional development and instructional program, Agile Mind's online system enables math educators to test curricular materials and pedagogical practices and investigate their impact on student learning. As members of an online learning community, teachers feed their observations (and students' results) back into the system—thus strengthening the knowledge base of the entire community and capitalizing on the wide range of teacher experience and skill. Within a context of shared learning, teachers are beginning to re-conceive their roles: rather than working as independent "composers" of lesson plans and other curricular materials, they are functioning more effectively, and with better results for students, as highly skilled "conductors" of student learning.

Tools developed by Wireless Generation, led and cofounded by Commission member Larry Berger, also use technology in innovative ways to promote teacher collaboration. Wireless Generation's FreeReading.net Web site, for example, is a wiki-based, open source literacy instructional hub where elementary school teachers can find, share, and modify lesson plans and see demonstration videos.

Teacher learning in science and math is also beginning to benefit from the more widespread engagement of master teachers in teacher preparation programs and ongoing professional development. A report by McKinsey and Company describes the practice in Singapore of giving teachers "individual feedback from the 2 to 3 percent of experienced, high-performing teachers who have been designated as peer coaches."[69] Math for America recruits a corps of "master teachers" from among experienced New York City public school math teachers; master teachers receive an annual stipend to "actively participate in professional development and mentoring" within the program and contribute to the "community of math teachers, sharing best practices and learning from one another's experiences." New Leaders for New Schools works with the principals it places to implement systems of distributed leadership at the school level, setting up instructional supports and career pipelines that engage teachers as mentors and leaders. New Leaders' model has produced significant improvements in many schools; overall, students in elementary and middle schools led by New Leaders principals for at least three years are making more rapid academic gains than comparable students in their districts by statistically significant margins.[70]

Professional learning in math and science could be organized around using, customizing, and perfecting a set of well-documented lessons and pedagogical approaches.

Other innovations are narrowing the gap between classroom practice and educational research, sometimes in ways that enhance math- and science-related professional learning for teachers. In a paper prepared for the Commission, Liz Gewirtzman described the "scaffolded apprenticeship model," developed by New Visions for Public Schools, which engages school teams in a process of inquiry that involves using data to identify subgroups of students who are not "on-track" to graduate, developing interventions to raise their performance, implementing the interventions, and monitoring effectiveness.[71] Conceived as a professional learning initiative (team members are nominally "apprenticing" for leadership positions and receive graduate credit toward an administrative credential), the program also provides teachers with powerful, practical training in statistics, experimental design, and the scientific method. The results in schools' ability to differentiate instruction for subgroups of learners have been significant: in 2007, New Visions graduated 77 percent of its students (all attending high-poverty schools) on time; by comparison, the citywide rate is 57 percent.[72]

3. On upgrading human capital management throughout US schools and school systems toward ensuring an effective teacher for every student, regardless of socio-economic background

As Odden and Kelly explain in their 2008 report on human capital management in education, "It is not sufficient for districts just to find top talent and turn them loose. As the private sector has learned over the past decade, the highest performance organizations not only recruit and retain top talent, but also manage them in ways that support the strategic direction of the organization."[73] For a school or school district to be effective, the authors continue, "top talent must be professionally managed around a well-designed educational improvement strategy."

The Commission urges schools and districts—and, indeed, states and the nation—to begin to manage explicitly against an overarching performance goal: dramatically increasing math and science learning for all students, a goal that is effectively a refinement of the more general goal of improving student performance across the board. As noted earlier, the Commission believes that science achievement in particular, because science is an integrative discipline that when it is well taught can serve as a benchmark for student achievement more generally, should be a focal point for the development of improvement strategies. Specific improvement strategies will be needed within each organization to advance that goal, and those strategies will inform the roles of teachers, school leaders, and others.

Performance management will mean, first of all, developing explicit strategies to retain the most effective teachers and facilitate the exit of those who are less successful. The school and school system leaders responsible for carrying out those strategies should be able to do so within the context of clear policies—policies that enable them to act consistently and in ways that reinforce the system's commitment to performance goals. As Odden and Kelly lay out, "when education systems create an instructional improvement strategy that includes a view of effective teaching strategies, those strategies should be embedded in all aspects of the system that have instruction at their core—day-to-day teaching, induction, professional development, mentoring and evaluation."[74] For more specific recommendations, they have developed case studies of districts that have undertaken comprehensive reform of human capital management systems. Cross-case findings show that "districts can move substantially toward solving teacher and principal quality and shortage problems" with a range of initiatives that include:[75]

- Actively recruiting more teachers and principals from top colleges and universities
- Partnering with talent recruitment organizations such as TNTP, TFA, and NLNS
- Growing their own teachers and principals
- Forging new relationships with local and high-quality colleges and universities
- Restructuring and automating the application, screening, and selection systems
- Moving the hiring calendar up to early spring

[73] Allan Odden and James A. Kelly (2008). "Strategic Management of Human Capital in Public Education," Consortium for Policy Research in Education.

[74] Odden and Kelly (2008).

[75] Odden and Kelly (2009). "Strategic Management of Human Capital 2.0," report to the Carnegie Corporation.

[76] C.T. Clotfelter, E.J. Glennie, H.F. Ladd, and J.L. Vigdor (2008). "Teacher bonuses and teacher retention in low-performing schools: Evidence from the North Carolina $1,800 Teacher Bonus Program," *Public Finance Review*, 36(1), 63-87. Richard M. Ingersoll and David Perla (2009). "The Mathematics and Science Teacher Shortage: Fact and Myth," CPRE Research Report #RR-62. American Institutes for Research, *Teacher Quality Research 2007*. air.org.

[77] Donald Boyd et al. (2008). "The Narrowing Gap in New York City Teacher Qualifications and Its Implications for Student Achievement in High-Poverty Schools," NBER working paper.

- Revising seniority transfers and eliminating seniority bumping
- Devolving selection decisions to school sites

The Commission recognizes that working conditions affect job satisfaction and are an important factor in teachers' decisions to stay in the field or leave teaching or their current positions—often as important as wages.[76] Retaining effective teachers is an especially important issue, requiring explicit management strategies, in schools with high proportions of low-achieving, poor, black, and Latino students.[77] This problem also affects rural schools, where small size places additional limits on schools' ability to hire science teachers with current knowledge and sufficient mastery of more than one science discipline. Differential retention of qualified teachers in mathematics and science, not necessarily the overall retention rate, is likely to have the greatest effect on students.

Our schools should also be learning deliberately to make better use of teacher compensation and benefits. The need is especially great in mathematics and science given chronic shortages in those fields and competition from other industries for talented, well-prepared professionals. In particular we need to study and experiment with alternatives to the basic "step-and-ladder" pay scale, including pay differentials, performance incentives, opportunities to take on leadership roles, and other strategies that might help schools attract and keep qualified mathematics and science teachers. The Commission encourages research and pilot programs to assess the potential need to introduce pay differentials for teachers with strong math and science backgrounds.

We need to study and experiment with alternatives to the basic "step-and-ladder" pay scale, including pay differentials, performance incentives, and opportunities to take on leadership roles

School and district leaders need to be attuned to the human capital requirements of high-quality science and math learning for all students. Leadership must manage flexibly to develop and fine-tune operations and human capital policies that meet the learning needs of students and the professional needs of teachers. Those leaders, in turn, need access to diagnostic and predictive tools that enable meaningful evaluation of teacher performance and the development of effective capacity building. States, districts, and the federal government must look for ways to reward excellence and stimulate innovation in our schools and classrooms. A new, rigorous, standards-aligned national system of assessments would be invaluable as we develop those experiments and study their results.

RECOMMENDED ACTIONS

The Commission recommends actions in three areas toward managing teachers and professional learning for effectiveness:

1. Increase the supply of well-prepared teachers of mathematics and science at all grade levels by improving teacher preparation and recruitment

By the federal government, states, and school districts

- Invest in the analysis of supply and demand for science and math teachers, especially in high-need school districts and schools
- Support recruitment programs for math and science teachers; experiment with scholarships and pay incentives
- Alter certification requirements to allow qualified candidates to enter teaching by innovative and rigorous alternative routes; enable museums, research institutions, and others to become teacher certifiers
- Develop integrated programs of professional learning and quality improvement for teachers of science and mathematics; engage all teachers in professional learning that enables them to incorporate science and math learning across the curriculum
- Make policy changes necessary to create an effective talent corps for schools, including principals and teachers, especially science and math teachers; encourage the dissemination of effective human capital management practices in areas such as teacher recruitment, hiring and retention, and compensation

By colleges and universities

- Design innovative, tailored science and math preparation routes that encourage and facilitate science and math majors to enter teaching
- Study program effectiveness through evidence from the student achievement by graduates of all programs, including math and science preparation
- Follow the early career experiences of graduates and strengthen communication with schools and districts to inform preparation and support for novice teachers
- Upgrade and increase required science and math courses for all undergraduates
- Review undergraduate curriculum and instruction in science and math to determine whether teacher candidates, and all college students, are experiencing the kind of high-quality instruction that they will need to repeat as teachers
- Strengthen connections with schools and school districts to improve effectiveness through shared mechanisms, such as setting strategic goals for clinical placement, and by involving science and math faculty along with experienced teachers in programs for future and practicing teachers
- Develop innovative teacher preparation and residency programs with education entrepreneurs

By businesses, nonprofit organizations, unions, and other partners

- Experiment with strategies to draw people with strong science and math backgrounds into teaching and increase their job satisfaction
- Press states to allow alternative credentialing by museums and other institutions

By philanthropy

- Support the strategic management of human capital with an emphasis on science and math teaching by states, districts, and educational entrepreneurs
- Support research on teacher recruitment and effectiveness, especially to identify factors relevant to science and math
- Support innovative strategies for new recruitment, retention, and certification pathways for science and math teachers

2. Improve professional learning for all teachers, with an eye toward revolutionizing math and science teaching

We must build a teaching profession in which all teachers, in every discipline and from the elementary grades on up, are "STEM-capable," or conversant with math and science.

By the federal government, states, and school districts

- Create and incentivize opportunities for teachers to experience powerful science and math learning themselves
- Cease support for professional development in science and math that is disconnected from teaching practices in schools; replace with investment in strategic and coherent collaborative offerings that link coherent, sustained professional learning, rich in relevant science and math content, to direct practice changes in instruction in schools
- Promote professional learning that engages teachers in data analysis, identification of students' differentiated learning needs, and assessment of school-level interventions
- Hold school leaders accountable for the professional learning environment in their schools and districts
- Strengthen partnerships with science-rich institutions; use those partnerships to open new learning opportunities for educators
- Invest in sophisticated online professional development systems that facilitate learning communities and cyberlearning by teachers, along with research to enable the improvement of those systems
- Expand the use of master teachers and other strategies that strengthen practice, encourage continuous learning, and improve career satisfaction

By colleges and universities

- Make the cultivation of STEM-capable teachers a university-wide priority, with visible board, executive, and cross-disciplinary faculty leadership
- Cease offering one-off university-designed and delivered professional development; replace with collaborative university-school designed strategies for upgrading teacher practice toward student learning outcomes
- Integrate preservice and ongoing learning by engaging skilled teachers in teacher preparation
- Share resources and assets (such as syllabi, online labs) publicly; encourage use by science and math teachers

By businesses, nonprofit organizations, unions, and other partners

- Build systems that enable teachers to use and contribute to a common knowledge base of curricular material and pedagogical techniques in science and math
- Develop programs that engage teachers in collaborating with scientists, mathematicians, engineers, museum educators, and others
- Provide learning opportunities that enable teachers to experience real-world science and math and apply to instructional improvements
- Create innovative preparation programs and teacher residency programs

By philanthropy

- Support innovative program models for ongoing professional learning in science and math that include assessment of student learning and mechanisms for improving professional learning based on evidence
- Fund research on the effectiveness of different professional learning models and platforms (cyberlearning, partnerships with science-rich institutions, teacher inquiry) on student and teacher performance in science and math

3. Upgrade human capital management throughout US schools and school systems toward ensuring an effective teacher for every student, regardless of socio-economic background

By the federal government, states, and school districts

- Make higher science and math achievement the overarching goal for system improvement; structure specific improvement strategies to meet that goal
- Experiment with strategies to improve job satisfaction of effective teachers of science and math at all grade levels
- Raise compensation strategically to attract, retain, and reward effective science and math teachers; compare different methods
- Develop data systems that enable meaningful teacher assessment on student achievement
- Identify and promote leadership opportunities (such as positions as coaches and mentors) for teachers with demonstrated effectiveness in raising student achievement in mathematics and science
- Give effective teachers a more prominent voice in education policy development

By colleges and universities

- Increase and improve connections with school districts and schools to follow the experiences of graduates who are teaching and to determine what resources and tools universities might provide that would support teachers, enrich science and math learning, and raise teacher effectiveness
- Upgrade the effectiveness of teacher preparation programs by tracking achievement data for students taught by program graduates

By businesses, nonprofit organizations, unions, and other partners

- Develop new programs to assist schools and districts improve management systems and teacher working conditions

By philanthropy

- Support research on the human capital management needs of schools and school systems, especially related to science and math

Schools and districts need to manage human capital as part of an educational improvement strategy that takes seriously the practical challenges of raising all students to higher levels of proficiency.

[78] David T. Conley (March 2007). *Toward a More Comprehensive Conception of College Readiness*. Prepared for the Bill and Melinda Gates Foundation. Educational Policy Improvement Center, University of Oregon. cepr.uoregon.edu. Conley defines college readiness as "the level of preparation a student needs in order to enroll and succeed—without remediation—in a credit-bearing general education course at a postsecondary institution that offers a baccalaureate degree or transfer to a baccalaureate program."

[79] Susan Goldberger, with Katie Bayerl (January 2008). "Beating the Odds: The Real Challenges Behind the Math Achievement Gap—and What High-Achieving Schools Can Teach Us About How to Close It." Jobs for the Future. Prepared for the Carnegie-IAS Commission On Mathematics and Science Education. Jff.org.

[80] New Visions for Public Schools, for example, sought to build high expectations and engagement into the design of its New Century High Schools by establishing ten "design principles" to guide the work of school creation teams. Eileen M. Foley, Allan Klinge, and Elizabeth R. Reisner (October 2007). *Evaluation of New Century High Schools: Profile of an Initiative to Create and Sustain Small, Successful High Schools*. Policy Studies Associates, Inc. newvisions.org/schools/downloads/PSAfinal92707.pdf.

SCHOOLS AND SYSTEMS: DESIGNING FOR ACHIEVEMENT

The Commission recognizes that calling upon the United States to bring far greater numbers of young people to much higher levels of mathematics and science learning represents a challenge higher than our educational system has ever committed to as a goal or come close to realizing as an achievement. The goal of dramatically upgrading math and science education aligns with similar calls and efforts for transforming American education to bring all students to "college readiness."[78] Mathematics is both a critical gateway subject and competence for college preparation and technical careers and a foundation of higher-order thinking. The sciences provide both methods for problem solving and core knowledge needed in our complex society for carrying out key civic responsibilities such as serving on a jury (which increasingly involves weighing science-based evidence) or voting on social issues such as stem cell research.

Daunting as this goal may be, it is essential to our national well-being. As a practical matter, therefore, we must make crucial decisions regarding changes to make, innovations to seek, public policies to craft, and investments to budget for and prioritize. We will need transformation at every level: systems, schools, and classrooms.

OBJECTIVES

- Build high expectations for student achievement in mathematics and science into school and classroom culture and operations as a pathway to college and careers
- Enhance systemic capacity to support strong schools and act strategically to turn around or replace ineffective schools
- Tap a wider array of resources to increase educational assets and expand research and development capacity

DISCUSSION

Schools must become more powerful learning organizations, where students engage in the practice of mathematics and science to build their knowledge and skills and incorporate prowess in math and science as part of their developing identities. This is especially clear for middle and high schools, which many American students enter already significantly under-prepared for academically rigorous work. These students have traditionally been relegated to a lower-track curriculum, resulting in their earning a second-class diploma or dropping out of school. This dual track exists in some states and districts even today. For these students, math and science education typically ends before they have had a chance to study algebra and any lab science.

In the current wave of high school reform, new schools have been created, and existing schools redesigned, where students who entered under-prepared are successfully studying curricula that can effectively prepare them to succeed in college.[79] A visitor to these schools will see that they have certain characteristics in common. Most immediately noticeable is an ethos of high expectations, engagement, and effort—a combination that enables teaching practices that bring students with diverse assets, needs, and competencies to high levels of science and math knowledge and skills. These schools also focus squarely on teaching and learning in all functions, including instruction, assessment, and professional development. They are personalized to engage students, motivate them to achieve, and meet their learning needs. They promote positive student culture and family engagement focused on student attainment of key goals, including college and career success.[80]

Another lesson from schools that are succeeding with under-prepared students is the importance of organizing more coherently to promote professional communities of principals and teachers—communities that build internal capacity and facilitate internal accountability. It is also common to find that these schools have taken steps to increase their intellectual and social capital through partnerships with scientific and cultural institutions, businesses, higher education, and community organizations; their boundaries are more "porous," and the entire school community benefits from stronger connections to the world outside the conventional schoolhouse walls. They are far more entrepreneurial about establishing pathways to higher education and careers and more receptive to collaboration. Their operations are transparent and accountable.

This is a high bar to set for individual schools, but such expectations are not unreasonable. Effective schools are already meeting them, at least most of the time, and working hard at doing even better. Providing an effective school for every student is a challenge we must meet, but doing so will require stronger systems—and systemic change.

At the ground level, many school districts lack the capacity to set objectives, focus disparate resources, and prioritize their efforts—necessary conditions for supporting higher school-level performance.[81] Rather, a combination of inefficient policies, bureaucratic rules and practices, outdated collective bargaining rules, and multiple disjointed initiatives weaken mid-performing schools and leave low-performing schools to flounder. Improving these crucial management capacities is essential to our country's success in developing schools that can bring large numbers of under-prepared middle and high school students to high levels of math and science achievement. Redesigned school systems would build the capacity of individual schools, protect school-level educators from distractions, and provide them with management support. More effective school systems would also close persistently failing schools and replace them with new promising models, encouraging educational entrepreneurship, innovation, and accountability. Every school would receive support in accessing the resources, tools, and incentives they need to bring all students to the higher levels of achievement defined by new, higher standards.

1. On building high expectations for student achievement in mathematics and science into school and classroom culture and operations as a pathway to college and careers

The Commission believes that we must view every element of school's design as a potential asset that can be brought to bear flexibly to improve instruction and foster positive adult–student relationships that increase student achievement, motivation, effort, confidence, and persistence—crucial for learning math and science and aspiring to higher education.[82] Motivation is often cited as teachers' biggest problem, the source of student alienation and apathy, classroom management problems, and the lack of shared commitment between teachers and students. To ensure that reform reaches those students who are now far from performing at high levels in academically rigorous courses in math and science in middle and high school, schools must be designed to incorporate lessons from research on youth engagement, motivation, and factors that promote resiliency in youth living in high-poverty, high-risk environments.

The fundamental insight driving the Commission decision to include a focus on school design is that dramatically increasing the motivation of middle and high school students toward high achievement in science and math requires attention to the two primary tasks of adolescence: building competencies and forming an identity. Increasing student motivation and effort must address both of these tasks, which research tells us are interactive. School design for higher math and science achievement must first recognize that research on engagement has identified the counterintuitive finding that students who are academically struggling and those who are disconnected from school make more progress and are motivated to make more effort and to persist when they are engaged by caring teachers in more academically challenging course work.[83] Science and math content that is presented in ways that engage students in active, often cooperative work with interesting material is essential.

[81] Ellen Foley and David Sigler (Winter 2009). "Getting Smarter: A Framework for Districts." *VUE 22, Redesigning the "Central Office."* Annenberg Institute for School Reform. annenberginstitute.org/VUE/archives.php.

[82] Organizations that have concentrated on developing, refining, and replicating new school designs include New Visions for Public Schools (newvisions.org); the New Technology Foundation, which replicates the New Technology High School model originally developed in Napa, California (newtechfoundation.org); Urban Assembly (urbanassembly.org); and Green Dot Public Schools (greendot.org). See their Web sites for examples of school models.

[83] National Research Council (2004). *Engaging Schools: Fostering High School Students' Motivation to Learn*, chapter 2, "The Nature and Conditions of Engagement."

[84] National Research Council (2004). *Engaging Schools*, Chapter 4, "Climate, Organization, Composition, and Size of Schools."

[85] W. Norton Grubb and Jeannie Oakes (October 2007). *Restoring Value to the High School Diploma: The Rhetoric and Practice of Higher Standards*. epsl.asu.edu/epru/documents/EPSL-0710-242-EPRU.pdf. Grubb and Oakes recommend a "multiple pathways" approach to high school reform, through the creation of schools "structured around a coherent theme, either broadly occupational or non-occupational."

Research on resiliency also makes clear that factors can be built into schools to boost the ability of students to overcome challenges associated with poverty, family stresses, or neighborhood conditions and focus on educational achievement.[84] These include caring relationships with adults who provide them with high expectations and demonstrate investment in their success, engaging activities where they have opportunities to practice skills and recover from errors, opportunities to make contributions to a group, and continuity of the adults in their lives who are committed to their success.

Traditional high schools, and many middle schools, have organizational characteristics—in their class schedules, number of students taught by each teacher each day, use of time, tracking of students into rigid ability groups, and other structures—that thwart rather than support resiliency.[85] Small schools and small learning communities, teaming, and clustering are school design elements that foster the ability of teachers and other school staff to know students well and promote a culture of trust, effort, and achievement—all of which are essential to learning math and science at high levels.

School designs that produce more powerful learning environments focus the school's assets on student learning and achieving the core mission. These assets include money, staff, time, size and schedules, calendar, data, performance targets and accountability measures, professional development, parent and community support, and student leadership. All need to be used effectively to increase motivation, expand the repertoire of instructional pedagogies and strategies used with different students, organize the school day and year, build in supports and opportunities that increase resiliency in students who experience failure and disconnection, and provide thoughtful opportunities for learning beyond schools. In reviewing each of these assets, schools should be asking how these components can be organized and blended to support learning science and math at academically rigorous levels.

School designs that produce more powerful learning environments focus the school's assets on student learning and achieving the core mission.

At the classroom level, innovation is needed so that math and science learning can be accelerated, made richer and more motivating, and connected more closely to students' lives. Classrooms will have to become energetic centers of math and science learning. Students and teachers need access to math and science instructional materials that are rigorous, rich in content, motivating, and clearly connected with the demands of further education, work, and family and community life. Math and science—but science especially because of its potential high interest to students—must be infused into other aspects of curriculum and school life.

Educators need expertise and support in using instructional techniques that address the learning needs of the diversity of American students at all grade levels. Schools must be designed to enable adults to assess students' learning needs and strengths and develop customized approaches to instruction (what activity, at what intensity and over how long, toward what end) to bring all students to high levels. This

is fundamentally a new kind of teaching and learning; it challenges teachers to possess and use a larger repertoire of instructional techniques, applied in alignment with the student's needs and the demands of the course work. Teachers need tools, including technology, that support assessment of students and development of differentiated approaches to instruction.[86] Schools must get better at meeting the learning needs of individual students, using methods that are more responsive and rigorous than those commonly employed today.

Teachers need access to excellent curricular materials derived from research on learning and improved mechanisms for sharing and refining resources. Teachers need the ability to form professional communities where excellence, identified by the student learning outcomes achieved, is valued and a source of professional learning for other teachers. Schools need to give science and math teachers access to formative assessments that are aligned to the standards and curriculum that are the focus of student learning, and they need access to master teachers to inform practice improvements.

Curriculum and classroom experiences must also be designed intentionally to connect with and bolster the connections for girls and for students of color to STEM opportunities and career pathways.[87] The Commission's finding from focus groups and surveys conducted by Widmeyer Communications that African-American and Latino students (8th and 10th grade) have higher than average interest in math and science but also few interesting classes and limited knowledge about the level of mastery needed for college and careers suggests an important motivational base but also a critical task for schools.[88]

Cyberlearning and associated technologies will also be essential. Students need and deserve access to Web sites and learning systems that reflect the expertise and creativity of our society. Such systems would ideally enable independent learning, thus encouraging and rewarding endless exploration by students and multiplying the value of teachers' time and expertise.[89]

2. On enhancing systemic capacity to support strong schools and act strategically to turn around or replace ineffective schools

We must simultaneously transform education at the federal, state, and local levels to become systems whose policies, funding, and regulatory practices support the development of more effective schools. To do this we will need smart, bold reform that ends failed policies and practices, manages human capital strategically toward performance objectives, and generates and fosters improvement, innovation, and invention to solve persistent problems of achievement gaps and plateaus.

Systems change would ensure that key design principles are in place in every school, and that schools orient their own operations toward managing efficiently, solving problems, and rewarding strong performance. School systems need increased

[86] Nora H. Sabelli (2008). "Applying What We Know to Improve Teaching and Learning." Prepared for the Carnegie-IAS Commission on Mathematics and Science Education. Sabelli calls for accelerating the development of new technologies that can improve student and teacher learning and support the reorganization of schooling for greater effectiveness. OpportunityEquation.org/go/sabelli.

[87] Shirley Malcom (2007). "Broadening Participation in STEM: Challenges and Opportunities." Prepared for the Carnegie-IAS Commission on Mathematics and Science Education. OpportunityEquation.org/go/malcom.

[88] Widmeyer Research and Polling (April 2009). "Attitudes toward Math and Science Education among American Students and Parents." Prepared for the Carnegie-IAS Commission on Mathematics and Science Education. OpportunityEquation.org/go/widmeyer.

[89] National Science Foundation Task Force on Cyberlearning (2008). ***Fostering Learning in the Networked World: The Cyberlearning Opportunity and Challenge, A 21st Century Agenda for the National Science Foundation***. nsf.gov.

[90] In New York City, for example, new small secondary schools created since 2002 are graduating approximately 70 percent of their students—nearly double the rate of the large, dysfunctional high schools they replaced. nyc.gov/ChoicesEnrollment/SpecialPrograms/default.htm.

capacity for research and development and for implementing new school models that push the limits of practice at both ends of the instructional spectrum: re-engaging our most disconnected students in academically rigorous science and math education and placing them on pathways to graduation and postsecondary education, and providing opportunities for the most successful students in science and math to accelerate beyond what is traditionally available in high school. Research and development efforts by states and districts can identify students in all of these situations and also identify "beat the odds" schools and programs that are demonstrating success in each of these categories.

School systems need increased capacity for research and development and for implementing new school models that push the limits of practice.

A research and development approach to school system design means that innovation and experimentation need to be encouraged within a standards and accountability framework. There is much to learn about the most effective school designs for realizing high levels of achievement in science and math by all. Urban districts including New York City, Chicago, and Los Angeles are closing their lowest performing high schools and replacing them with a mix of small schools designed and developed by charter operators, nonprofit school development organizations, higher education institutions, and scientific and cultural organizations. These schools must meet state standards and are often required to be developed according to "design specifications" based on research on the characteristics of effective schools. Many emphasize science, math, and technology both in their curriculum and in the partnerships they form with scientific and health institutions and industry.

These new urban schools are educating large numbers of high-poverty students and showing substantial gains in academic achievement and graduation rates compared to the schools they replace.[90] Some models are also oriented to identifying students with strong academic skills in science and mathematics and giving them access to intensified course pathways to STEM higher education and STEM careers. These specialized schools are also important developments, for students and their families gain when a variety of models are available. School systems benefit, too, when they have opportunities to learn from a "portfolio" of different school designs. School and systems need opportunities to be thoughtful about tactics and change tactics if something isn't working.

Redesigned systems would adopt assessments aligned to higher standards and design and deploy accountability systems that reward effective instruction. More effective school systems would make designing and maintaining well-functioning human resource management a high priority. Recruiting, developing, and retaining high-capacity principals and teachers and moving out those who do not meet those criteria are essential to the development of schools that deliver on the promise of excellence and equity. Developing and sustaining research and development capacity would also enable redesigned systems to manage the changes needed to sustain and replicate high-performing schools, improve middle-performing schools, and redesign, turn around, or replace low-performing schools.

3. On tapping resources outside the school system to increase educational assets and research capacity

The Commission believes, as well, that achieving greater effectiveness in mathematics and science education will require infusions of fresh ideas, assets, and partnerships. For example, new organizations and types of organizations have entered the field to sponsor public schools over the last several years, often bringing new ideas that overturn conventional assumptions and strengthen public schools overall.[91] This is a trend that could continue to enrich the field, and the Commission would especially welcome new entrants that focus specifically on math and science learning. New partnerships between K-12 and higher education, museums, and community and cultural organizations, as sponsors of or partners to public schools, will also be essential.

System change also requires intentional engagement in new forms of partnership that are focused on raising science and math achievement.[92] Scientists and mathematicians, students and parents, scholars and researchers, businesspeople and employers, elected officials, and many others will be needed for a successful national push. Universities, museums and other "science-rich" institutions, after-school and summer programs, and business and professional associations all have resources to add to the endeavor.[93] We also need to look more systematically at opportunities for learning offered to students beyond the school building and the school day. We need a stronger and more accessible infrastructure for supporting out-of-school-time programs, apprenticeships, and other vehicles that increase student motivation, incentivize and reward initiative, and strengthen students' connections with higher education and employment.

We will also need to cultivate new system functions within and across districts, states, and national networks. Education has long suffered from a lack of high-quality, dedicated research and development capacity. One response is the Strategic Education Research Partnership (SERP), which is attempting to fill the gap through collaborative field clusters focusing on specific locations or research-practice priorities (currently Boston, San Francisco, and minority student achievement).[94] SERP has begun to work with school districts to select problems in need of investigation; form interdisciplinary teams of researchers, developers, and practitioners; and conduct rigorous scientific evaluation of student achievement. SERP has adopted a set of prerequisites, or conditions that need to be "present from day 1," that are intended to ensure that research projects are responsive to district needs and likely to gain traction in schools and classrooms:

- Commitment of top district leadership to the field site collaboration
- Focus on problems of importance to the district
- Ability to bring high-quality knowledge resources to the table
- Ability to effectively coordinate and steer the work to maintain productivity

[91] The Brooklyn Botanic Garden, for example, established the Brooklyn Academy of Science and the Environment High School (BASE) in 2003 in collaboration with the New York City Department of Education, New Visions for Public Schools, and the Prospect Park Alliance. A small, public high school, BASE uses the Garden and Prospect Park for extensive field study activities by students. www.bbg.org/edu/base.html.

[92] A prime example of an ambitious new public–private partnership is the National Math and Science Initiative (NMSI), founded in 2005 with significant lead funding from Exxon-Mobil Corporation, joined by the Michael and Susan Dell Foundation and the Bill and Melinda Gates Foundation. UTeach and Advanced Placement Strategies are also founding members, and NMSI has begun to invest in a significant, multi-state scale-up of their services, along with other strategies to improve K-12 math and science education. nationalmathandscience.org.

[93] American Museum of Natural History (May 2009). Emboldened Capacity: Science Education and the Infrastructure of Science-Rich Cultural Institutions. Prepared for the Carnegie-IAS Commission on Mathematics and Science Education. OpportunityEquation.org/go/amnh.

[94] Information on SERP and current field research is available at serpinstitute.org.

[95] See hbs.edu/pelp.

- Ability to "flatten the field" so that all sources of expertise are held in high regard and the culture is one of mutual respect

There has also been an uptick in commitment to management-oriented education research by universities. The Public Education Leadership Project, a collaboration between Harvard's School of Education and Business School, draws on faculty from both schools to study leadership and management practices that support large-scale organizational change in urban school districts.[95]

Finally—and this will be as important as anything to our long-term success—the American educational system must upgrade its own capacity to innovate. We need to get smarter about developing and testing new ideas, tapping and advancing professional knowledge, and putting best practices to use.

We also need to look more systematically at opportunities for learning offered to students beyond the school building and the school day.

RECOMMENDED ACTIONS

The Commission recommends actions in three areas toward designing schools and school systems for mathematics and science achievement:

1. Build high expectations for student achievement in mathematics and science into school and classroom culture and operations as a pathway to college and careers

By states, school districts, and charter organizations

- Foster an ethos and culture emphasizing high expectations for math and science achievement by all students within each school and assess specific indicators of that culture using methods such as School Quality Reviews
- Organize schools to focus on teaching and learning as their core mission with a strong emphasis on science and mathematics; enable schools to focus their resources (money, time, people) flexibly and accountably on increasing student performance
- Build data-driven instructional improvement and innovation into the culture and professional learning of each school
- Develop tools and technologies that enable students and families to track student progress and plan for the future with key indicators in science and math achievement linked to college-readiness
- Explore and assess technology-based learning innovations in science and math learning, including digital media and games; document and expand those that show positive results; invest in promising cyberlearning to allow all teachers to support and reinforce student learning using new educational technologies

2. Enhance systemic capacity to support strong schools and act strategically to turn around or replace ineffective schools

By the federal government, states, and school districts

- Create aligned data, accountability and knowledge management systems

Providing an effective school for every student is a challenge we must meet, but doing so will require stronger systems—and systemic change.

across K-16 education to support research and development for improvements in policy, practice, and strategy to increase student achievement, graduation, and post-secondary success; ensure that science achievement is included in the early generation models

- Develop data and accountability systems that enable schools to use data to inform instructional improvement by individual teachers and school-wide; data on science achievement, especially in middle and high schools
- Make the policy and management changes to generate and accelerate innovation, and facilitate connections to increase the talent and math and science assets available in schools
- Foster a more rigorous approach to ongoing professional learning in many more districts, focused on keeping teachers up to date with emerging science and math knowledge and on effective, differentiated pedagogical techniques
- Make policy changes and take administrative action to end policies and practices that result in persistent low achievement, and, in particular, close and replace schools that are low-performing
- Stimulate the production of ideas and products that will support school and classroom innovations to increase math and science achievement through a variety of public funding sources beyond education including economic development, energy, and environmental quality departments
- Identify school models and innovations in school design and instruction that have shown substantial achievement gains in mathematics and science, especially for under-performing middle and high school students
- Remove barriers and pro-actively grow and scale effective school models through innovative governance and management arrangements with educational entrepreneurs; integrate with strategic human capital reforms
- Call for research in areas where innovations do not exist or where there is a need for new knowledge, including basic research, implementation research, and tool development to advance math and science learning

3. Tap a wider array of resources to increase educational assets and expand research and development capacity

By the federal government, states, school districts, colleges and universities, and philanthropy

- Narrow the gap between research and practice in improving science and math education by designing innovative partnerships between K-12 education and universities, cultural and scientific institutions that are accountable for joint strategies for improving student achievement
- Bring innovation and design approaches to bear on improving math and science education in the K-12 educational system by developing R&D capacity and external resources (such as consulting firms, private-sector companies, universities)

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The Commission urges schools and districts—and, indeed, states and the nation—to begin to manage explicitly against an overarching performance goal: dramatically increasing math and science learning for all students.

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