E2E – Engage to Excel: An Overview of the Second PCAST STEM Ed Report

S.J.Gates, Jr.
John S. Toll Professor of Physics and
Center for String and Particle Theory Director

04 June, 2012

University of Maryland, Physics Department, Rm 4121, College Park, MD 20742-4111
301-405-6025 http://www.umdphysics.umd.edu/people/faculty/135-gates.html

What is PCAST?

- PCAST is an advisory group of the nation's leading scientists and engineers who directly advise the President and the Executive Office of the President.

- PCAST makes policy recommendations in the many areas where understanding of science, technology, and innovation is key to strengthening our economy and forming policy that works for the American people.

Who is PCAST?

Co-Chairs

John P. Holdren
Assistant to the President for
Science and Technology; Office of Science and Technology Policy

Eric Lander
Broad Institute of Harvard and MIT

Vice Chairs

William Press
University of Texas at Austin

Maxine Savitz
National Academy of Engineering
•

Members

Rosina Bierbaum
University of Michigan

Christine Cassel
American Board of Internal Medicine

Christopher Chyba
Princeton University

S. James Gates, Jr.
University of Maryland, College Park

Mark Gorenberg
Hummer Winblad Venture Partners

Shirley Ann Jackson
Rensselaer Polytechnic Institute

Richard C. Levin
Yale University

Chad Mirkin
Northwestern University

Mario Molina
University of California, San Diego

Ernest J. Moniz
Massachusetts Institute of Technology

Craig Mundie
Microsoft Corporation

Ed Penhoet
Alta Partners; University of California, Berkeley

Barbara Schaal
Washington University, St. Louis; National Academy of Sciences

Eric Schmidt
Google, Inc.

Daniel Schrag
Harvard University

David E. Shaw
D.E. Shaw Research;
Columbia University

Ahmed Zewail, California Institute of Technology

PCAST expertise requested by Obama Administration

- **PCAST studies requested and completed:**

– The science and technology of the 2009-**H1N1 Influenza**
– Reengineering the **Influenza Vaccine Production** Enterprise
– Assessment of the **National Nanotechnology Initiative**
– Prepare and Inspire: **K-12 STEM Education**
– Accelerating the Pace of Change in **Energy Technologies**
– Realizing the Full Potential of **Health IT** to Improve Healthcare
– Designing a Digital Future: **Networking and IT R&D** (NITRD)
– Ensuring American Leadership in **Advanced manufacturing**
– **Biodiversity preservation** and ecosystem sustainability
– Engage to Excel**: STEM Undergraduate Education** – the first two years

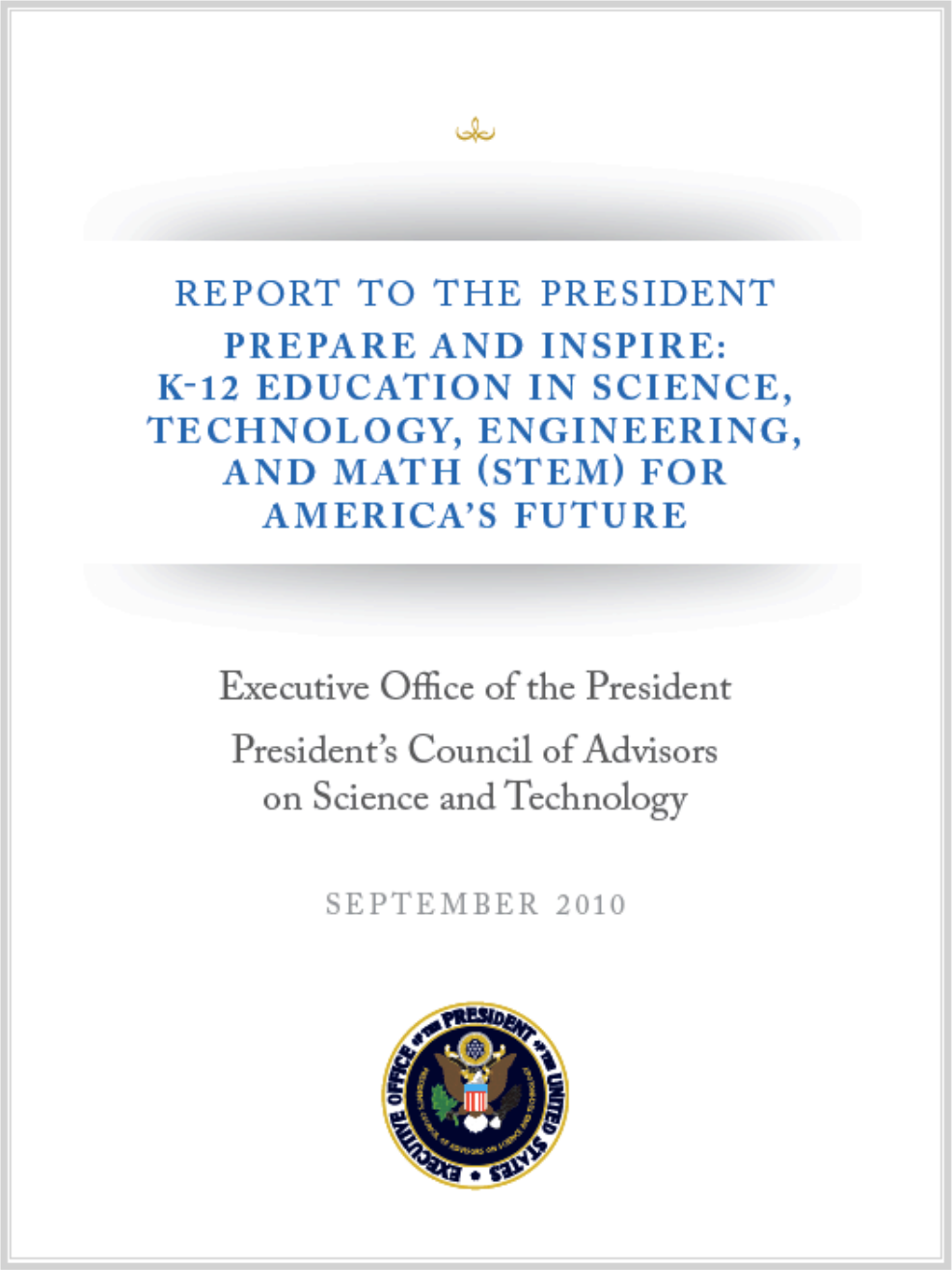
- **PCAST studies underway:**

– Propelling Innovation in **Drug Discovery, Development and Evaluation**
– **Advanced Manufacturing Partnership**
– Future of the **U.S. Science and Technology Research Enterprise**
– **Agriculture Preparedness**
– Realizing Full Potential of **Government-Held Spectrum** to Spur Economic Growth

- **No other president has asked PCAST to do so much so soon.**

Obama's PCAST has produced two reports on STEM education:

Prepare and Inspire:
K-12 Education in STEM for America's Future



REPORT TO THE PRESIDENT

PREPARE AND INSPIRE:
K-12 EDUCATION IN SCIENCE, TECHNOLOGY, ENGINEERING, AND MATH (STEM) FOR AMERICA'S FUTURE

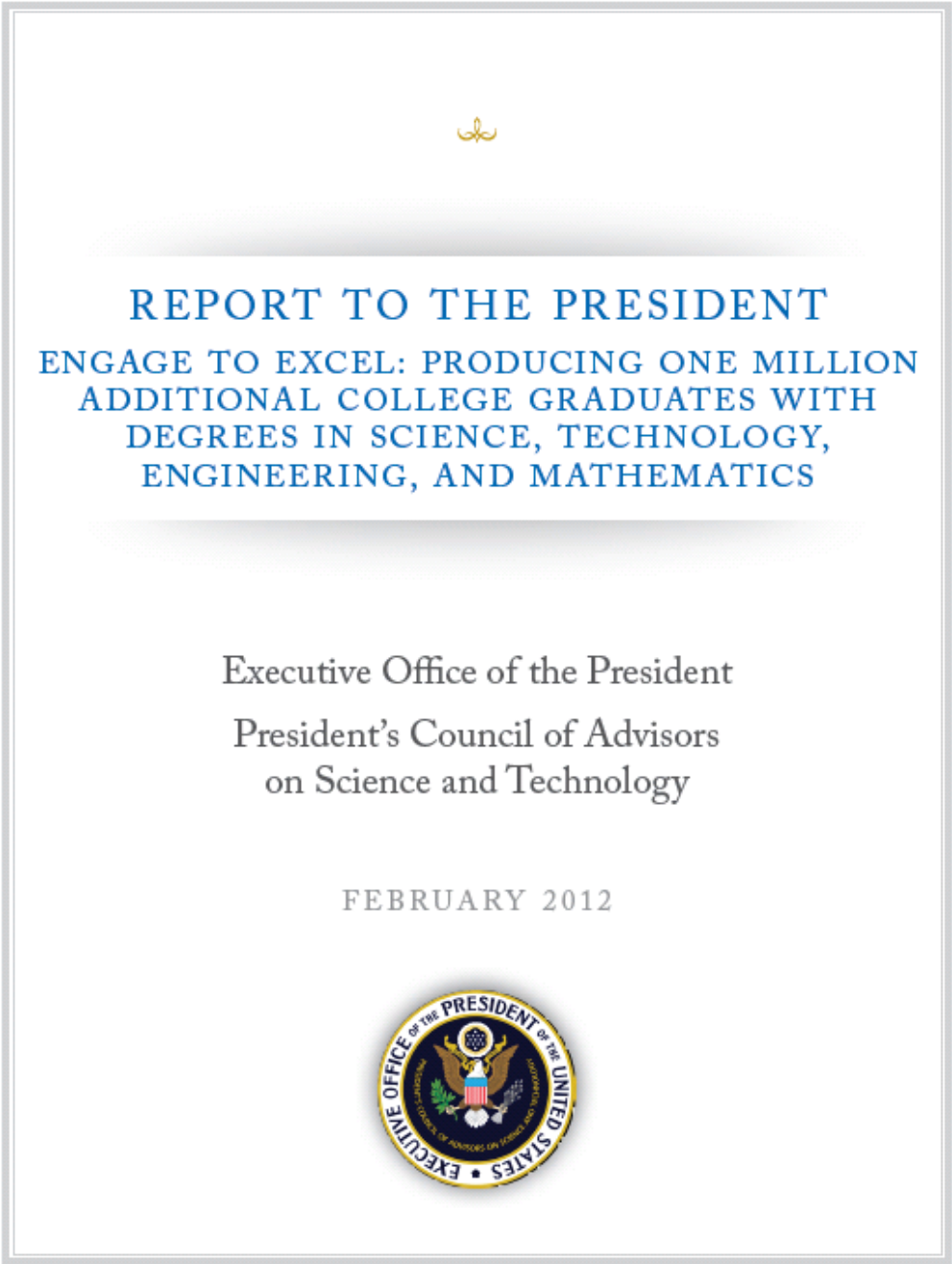
Executive Office of the President

President's Council of Advisors on Science and Technology

SEPTEMBER 2010

Obama's PCAST has produced two reports on STEM education:

Engage to Excel: Producing One Million Additional College Graduates with Degrees in STEM



REPORT TO THE PRESIDENT

ENGAGE TO EXCEL: PRODUCING ONE MILLION ADDITIONAL COLLEGE GRADUATES WITH DEGREES IN SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS

Executive Office of the President

President's Council of Advisors on Science and Technology

FEBRUARY 2012

Engage to Excel:

Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Math

The President's Council of Advisors on Science and Technology

PCAST STEM Undergraduate Education Working Group

Study Co-Chairs:

S James Gates Jr. (PCAST), University of Maryland

Chad Mirkin (PCAST), Northwestern University

Jo Handelsman, Yale University

G. Peter Lepage, Cornell University

PCAST members:

Shirley Ann Jackson, Rensselaer Polytechnic Institute

Ed Penhoet (PCAST), Alta Partners and Immune Design

Daniel Schrag, Harvard University

Working Group Members:

Joseph G. Altonji, Yale University

Peter Bruns, Howard Hughes Medical Institute (retired)

Carol Christ, Smith College

Isaac Crumbly, Fort Valley State University

Emily DeRocco, The Manufacturing Institute; National Association of Manufacturers

Brian K. Fitzgerald, Business Higher Education Forum

Neal Lane, Rice University

Tom Luce, National Math and Science Initiative

Judy Miner, Foothill College

Suzanne Ortega, University of New Mexico

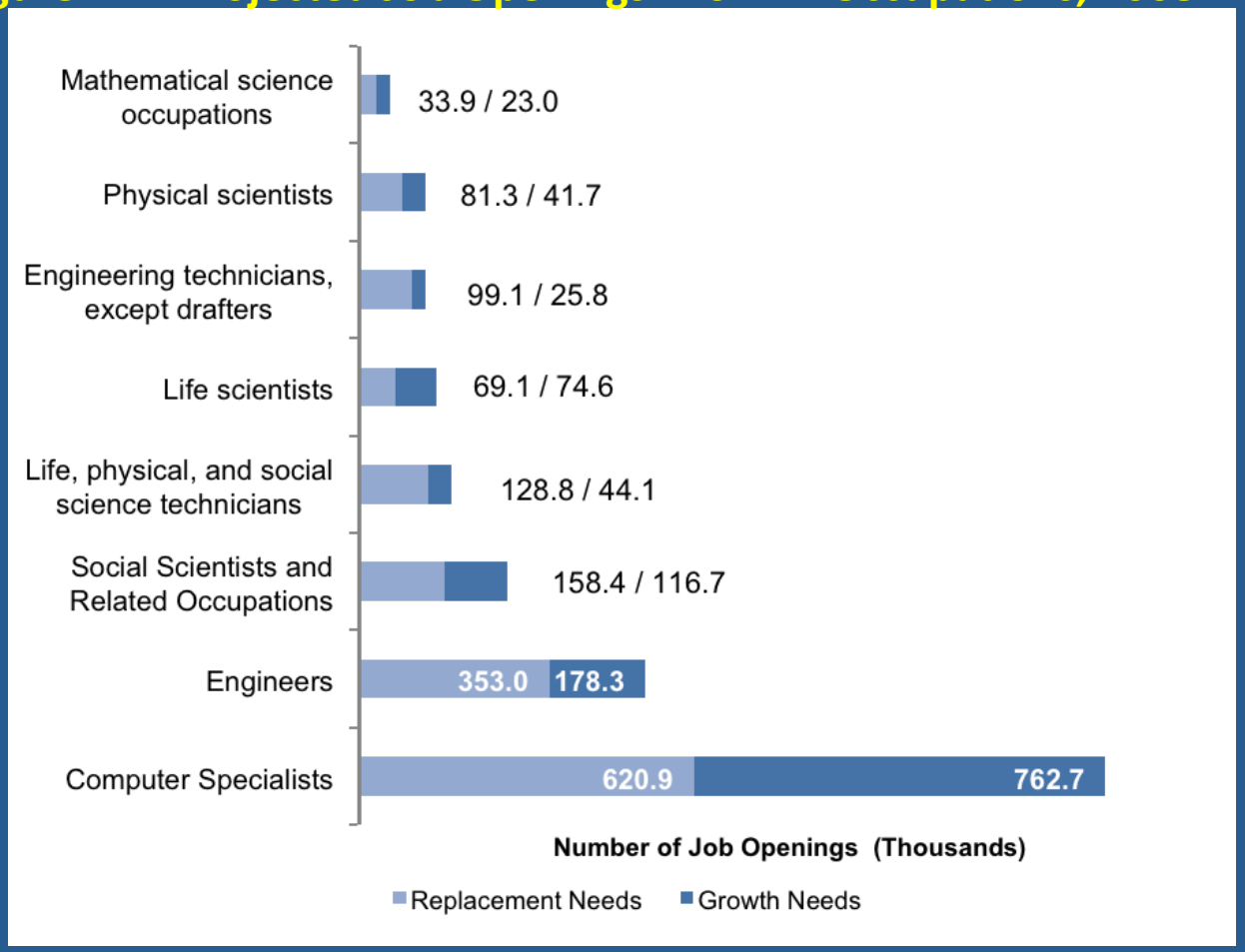
Calvin Phelps, National Society of Black Engineers (student)

Dan Schwartz, Stanford University School of Education

Candace Thille, Carnegie Mellon University

Help Wanted: STEM-capable workers

Figure D-7. Projected Job Openings in STEM Occupations, 2008–2018

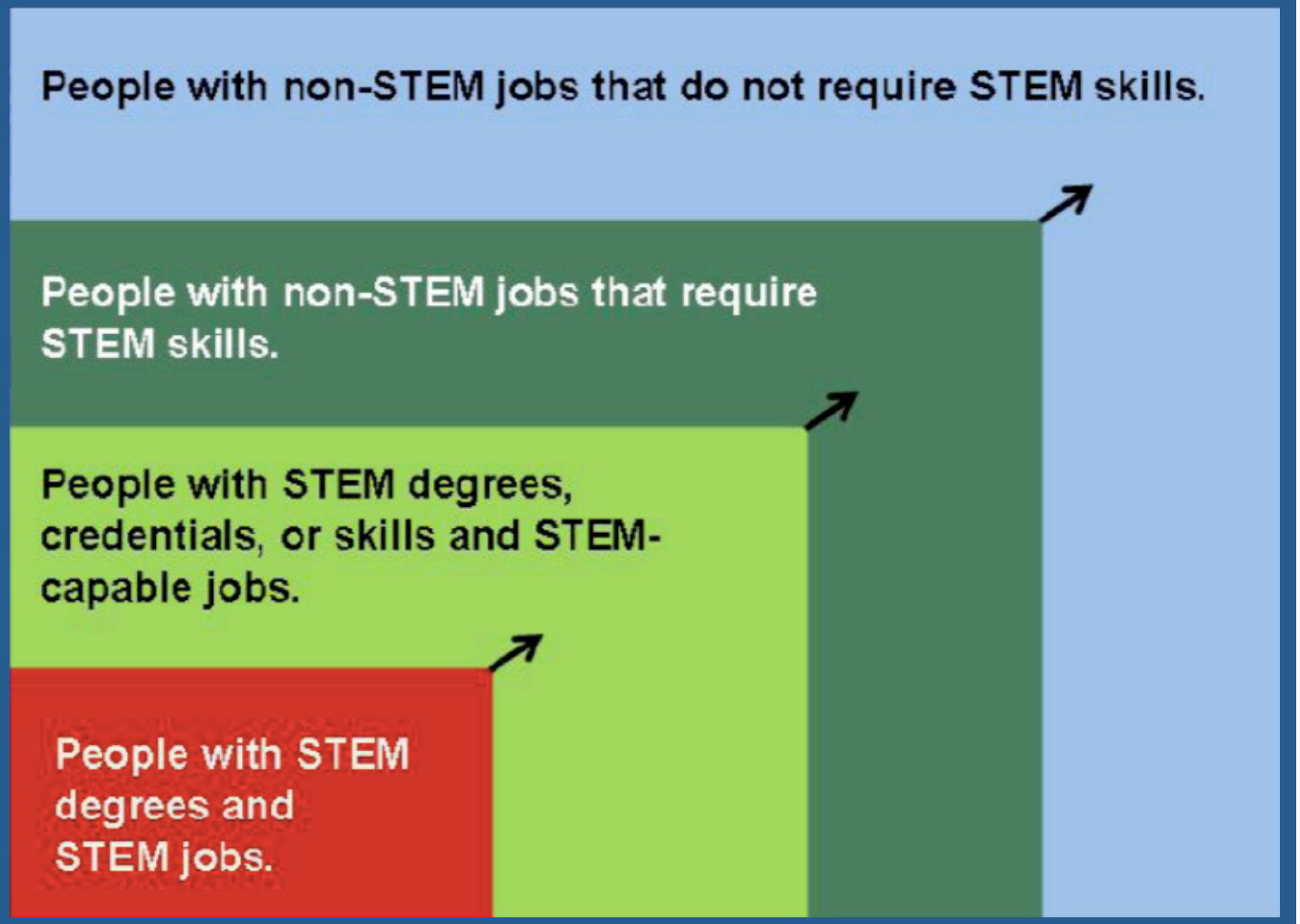


Derived from: Bureau of Labor Statistics. Analysis by IDA Science and Technology Policy Institute

- Between 2008 and 2018, STEM occupations will increase from 5.0% of the total jobs in the U.S to 5.3%, an increase that is equivalent to 1 million jobs.

STEM Skills are Needed in a Growing Number of Occupations

Figure E-1 Total U.S. Workforce



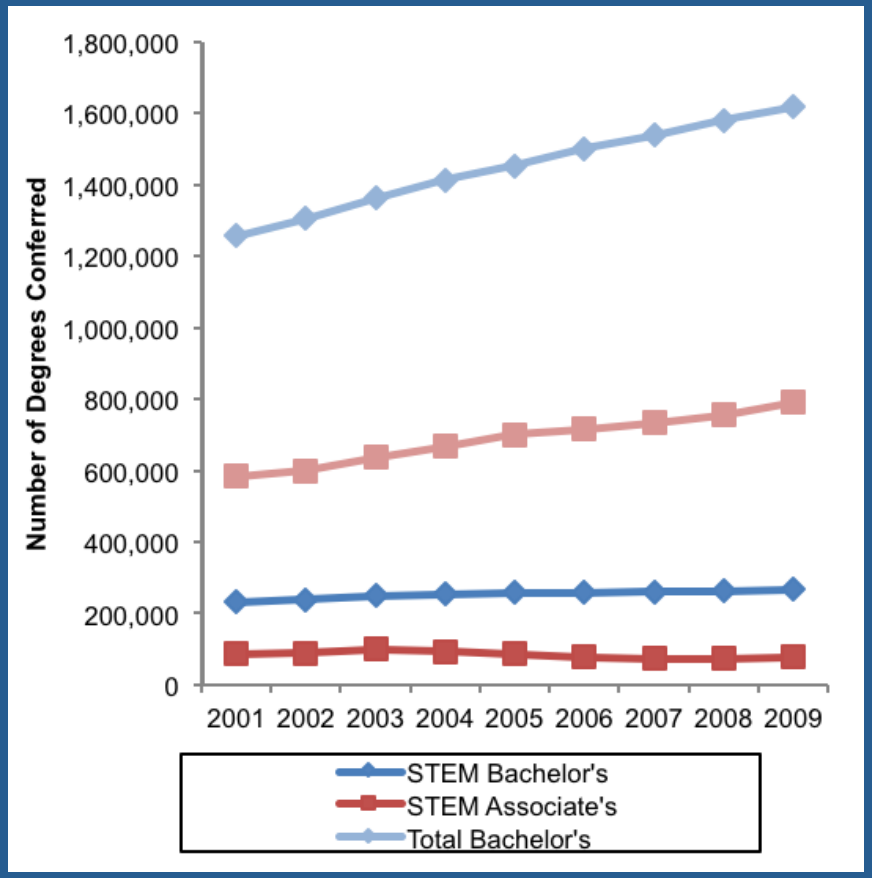
Some postsecondary education

Need additional 4-year and 2-year degrees and credentials

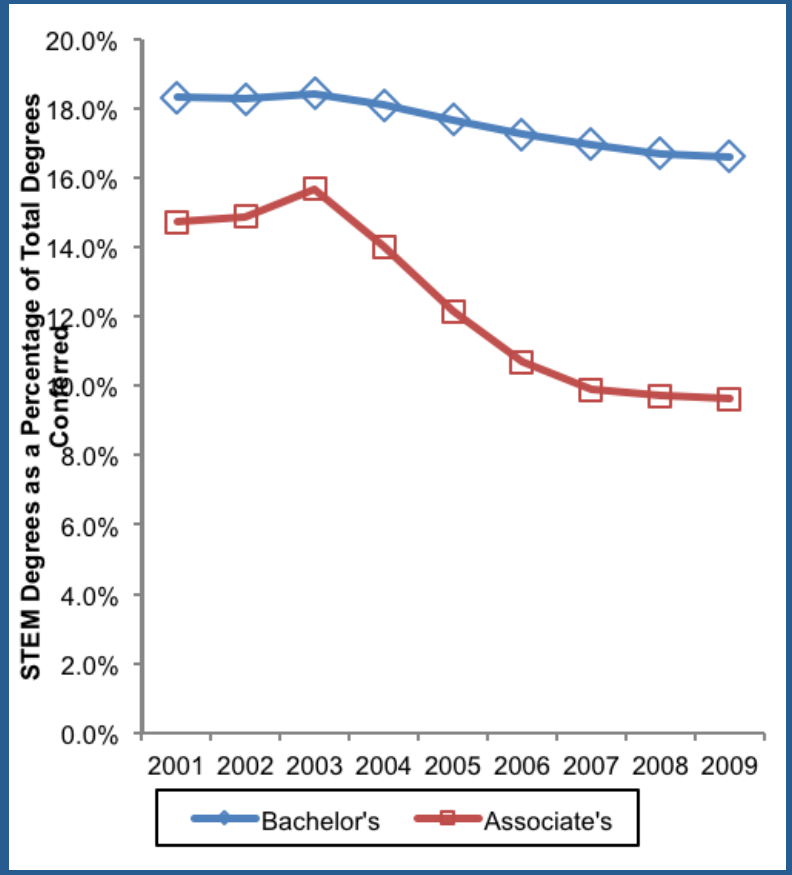
Need additional 4-year degrees in the next decade

STEM Degrees are NOT Keeping Pace

Number of STEM Degrees



STEM Degrees as % of Total Degrees



- STEM degree attainment has not kept pace with the growth in overall college degrees

Derived from: NCES, IPEDS, WebCASPAR

Low Numbers of (non-Asian) Ethnic Minorities Earning STEM Degrees

Table C-8. Percentage of Degrees Conferred by Race/ Ethnicity, 2009

	Percentage of Degrees Conferred in 2009										
		STEM Majors									
Race/Ethnicity	STEM Total	Life Sci	Physical Sci	Math	Comp/ Info Sci	Engineering/ Eng Tech	Sci Tech	Social Sci	Health Professions	Other Non-STEM	Total
White	14.4	4.9	1.1	0.7	2.7	5.0	0.1	9.7	12.3	63.5	100
Black	10.6	2.9	0.6	0.4	3.4	3.3	0.1	10.2	13.9	65.3	100
Hispanic	11.9	3.4	0.7	0.5	2.6	4.7	0.1	10.5	10.8	66.8	100
Asian/ Pacific Islander	23.0	10.0	1.7	1.1	3.0	7.1	0.1	12.5	11.0	53.5	100
American Indian/ Alaska Native	13.1	4.9	1.0	0.4	2.6	4.1	0.1	9.6	12.6	64.7	100

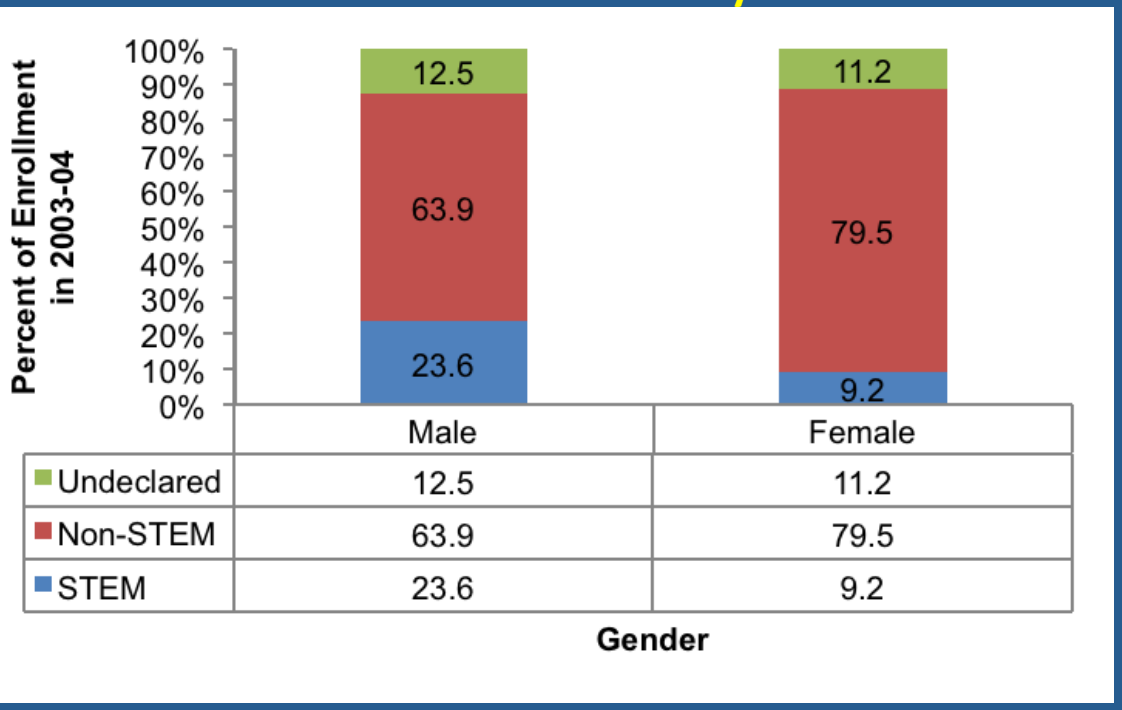
Derived from: NCES, IPEDS, WebCASPAR

Key Points (Table C-8):

- Across all race/ ethnicity categories, White and Asian/Pacific Islander students obtained STEM degrees at the highest percentages at 14% and 23%, respectively.
- Among underrepresented minorities, 10.6% of Blacks and 11.9% of Hispanics earned degrees in STEM.

Women Enroll in STEM Degrees at Low Numbers and Leave at High Rates

Figure C-7. Estimates of Enrolled Field by Gender

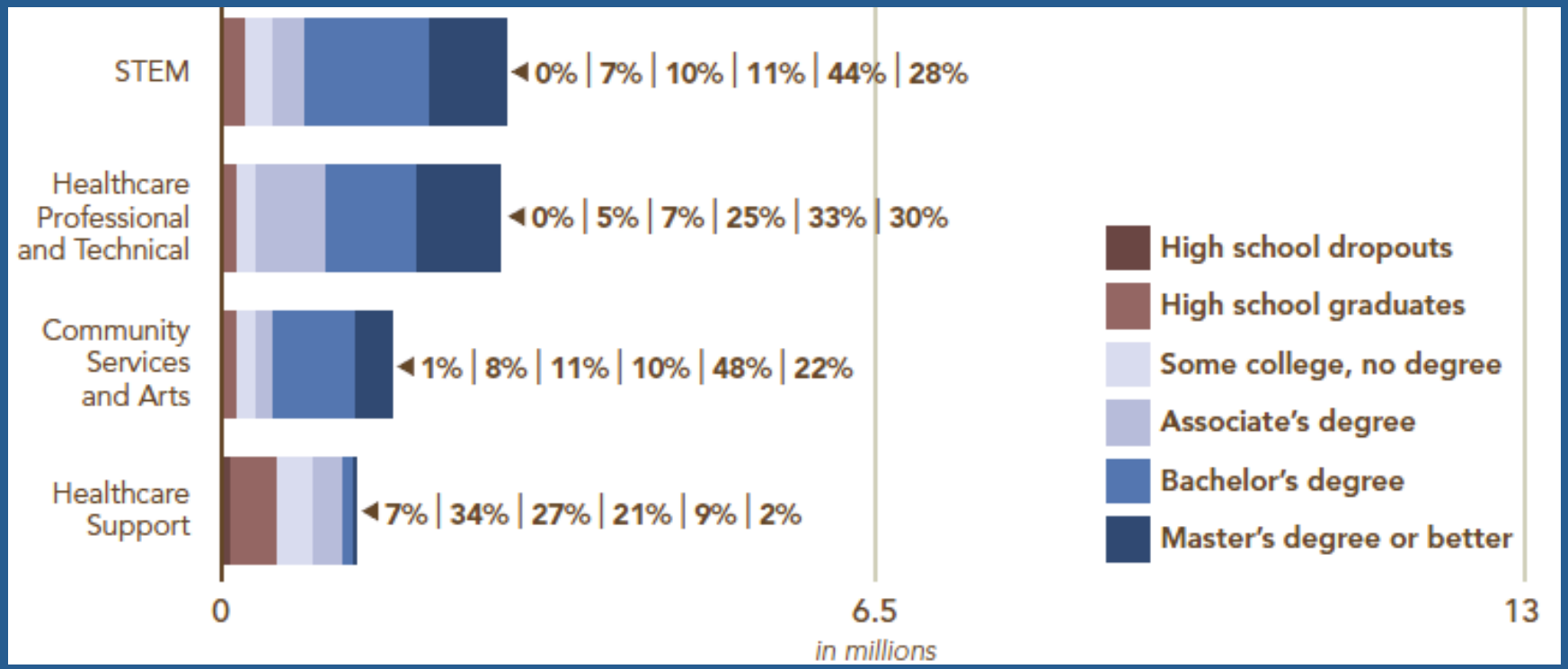


Derived from: U.S. Department of Education, National Center for Education Statistics, 2003-04 Beginning Postsecondary Students Longitudinal Study, Second Follow-up (BPS:04/09).

- Less than 10% of college women enroll in STEM fields, compared to nearly 24% of college men.
- Of those women who enroll in a STEM program, just over 5% earn a degree in a STEM field

The Importance of a STEM College Education

Figure D-6. Total Job Openings and the Distribution of Educational Demand within Occupations



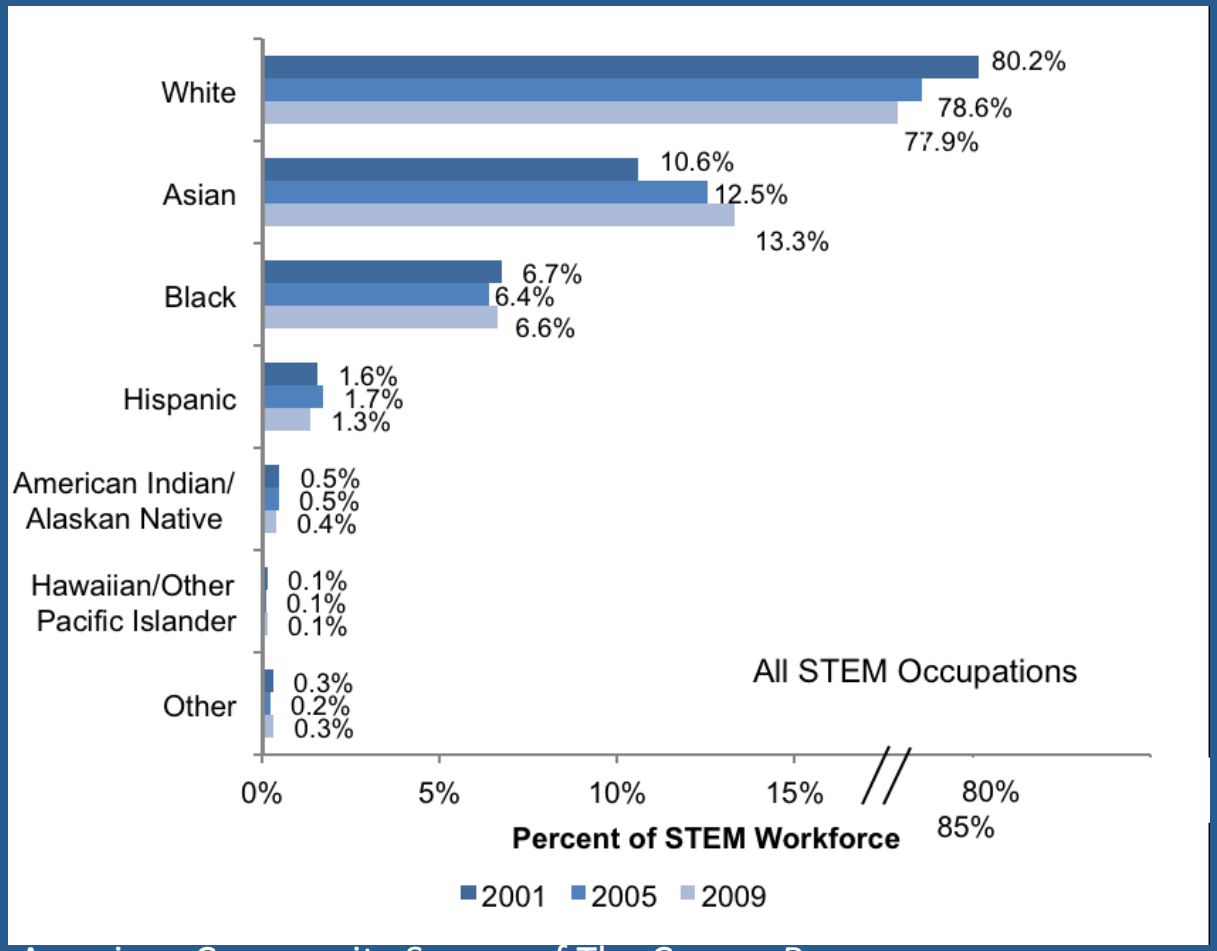
Source: Carnevale, A. *et al,* 2010.

By 2018

- More than 90% of STEM job openings will require some college
- 83% of STEM job opening will require at least an Associate's or Bachelor's degree.

STEM Workforce Diversity Still Lacking

Figure D-3. Estimated Race/Ethnicity of Labor Force in All STEM Occupations

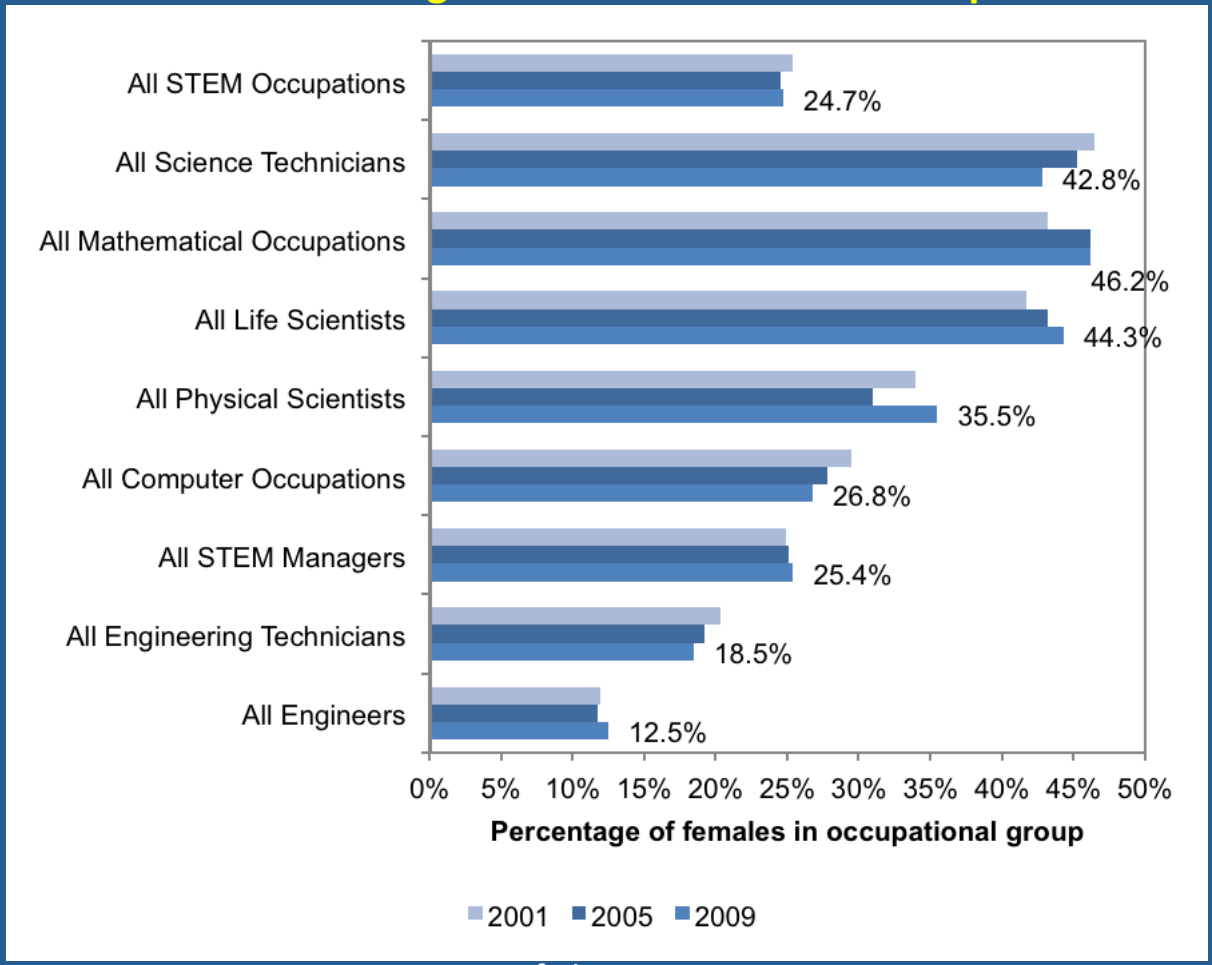


Derived from: American Community Survey of The Census Bureau

- Non-Asian Ethnic Minorities comprise less than 10% of the STEM workforce—with little to no gains in the last decade.

STEM Workforce Diversity Still Lacking

Figure D-2. Estimated Percentages of Females in STEM Occupational Groups



Derived from: American Community Survey of The Census Bureau

- Women comprise less than 25% of the total STEM workforce.
- Women populate around 45% of all mathematics and life science jobs while they make up only 12.5% of the engineering workforce.

Retention and Diversity Problems in STEM Undergraduate Education

- Fewer than 40% of students who enter college intending to major in a STEM field complete a STEM degree.
- High-performing students frequently cite uninspiring introductory courses as a reason for switching majors.
- Low-performing students with a high interest and aptitude in STEM face difficulty in introductory courses due to insufficient math preparation and help.
- Many students cite an unwelcoming atmosphere from faculty teaching STEM courses as a reason for their departure.
- Women and members of minority groups now constitute approximately 70% of college students, but earn only 45 percent of STEM degrees. They represent an "underrepresented majority" that leave STEM majors at higher rates than others and offer an expanding pool of untapped talent.

Engage to Excel -- Findings

Need one million more STEM professionals than will be produced at current rates over the next decade.

- Increasing the rate of STEM associate and bachelor degrees by 33% from 3 million to 4 million over the next decade will help satisfy the projected demand for STEM workers.
- First two years of college do not inspire students to pursue STEM degrees.
- Increasing retention from 40% to 50% would generate almost three-quarters of the one million additional STEM degrees needed in the next decade.

Engage to Excel – Findings (continued)

- Improved teaching methods, including engaging students in active learning, will increase student retention and improve performance in STEM courses.
- The current system delays hands-on research and internship experiences for STEM majors to the third and fourth year of college, when many of the students have already opted out.
- Closing the mathematics-preparation gap would enable many more students interested in STEM fields to attain STEM college degrees.
- Retaining more STEM majors is the lowest-cost, fastest policy option to provide the STEM professionals that the Nation needs for economic and societal well-being.

Imperatives to Improve STEM Undergraduate Education

Based on extensive research about students' choices, learning processes, and preparation, three imperatives underpin this report:

- Improve the first two years of STEM education in college.
- Provide all students with the tools to excel.
- Diversify pathways to STEM degrees.

Our recommendations detail how to convert these imperatives into action.

Engage to Excel

Multipronged Solution

- Capture the thrill of discovery and inquiry in the first two years of college STEM courses.
- Address the gap in math preparedness.
- Provide diverse routes to STEM degrees.
- Galvanize leadership in academic science to foster change.

These strategies have been shown to have an effect in increasing retention for all students, including the underrepresented majority.

Recommendation #1

Catalyze widespread adoption of empirically validated teaching practices.

Diverse active learning methods enhance learning

Case studies
Problem-based learning
Problem sets in groups
Concept mapping

Small group discussion & peer instruction
Analytical challenge before lecture
Computer simulations and games

Writing w/peer review
Testing
Clickers
Group tests

Examples:

- One study found that students in traditional lecture courses were twice as likely to leave engineering and three times as likely to drop out of college entirely compared with students taught using active learning techniques.
- Students in a physics class that used active learning methods learned twice as much as those taught in a traditional class, as measured by test results.

Recommendation #1
Catalyze widespread adoption of empirically validated teaching practices.

Premise:

Classroom practices that actively engage students promote learning better than lectures.

Existing Barriers:

- Most faculty lack experience using active learning methods and are unfamiliar with the vast body of research indicating their impact on learning
- The transition to empirically validated methods requires time and effort that can be costly for colleges and universities

Evidence of Success:

- Existing programs (National Academies, AAPT/APS/AAS) to train faculty have shown to change faculty behavior
- Scale-up and expansion across STEM disciplines is needed to share best practices

Recommendation #1

Catalyze widespread adoption of empirically validated teaching practices.

Actions:

Successful programs should be expanded to reach 10% to 20% of the nation's 230,000 STEM faculty over the next five years.

- Train current and future faculty in evidence-based teaching.
  - $10-15 million per year over 5 years for the training of 23,000 to 46,000 STEM faculty derived from Federal programs, academic institutions, disciplinary societies, and foundations.
  - To train future faculty, Federal research agencies should require all graduate students and postdoctoral fellows supported by federal training grants to receive instruction in modern teaching methods.
- Provide grants to enable campuses to adopt new teaching practices.
  - Create a "STEM Institutional Transformation Awards" competitive grants program.
- Develop metrics by which institutions can gauge their progress toward excellence in STEM education.

Recommendation #2

Advocate and support replacing standard laboratory courses with discovery-based research courses.

Premise:

Students who engage in research early in college are more likely to persist in STEM majors.

Example:

One study found that college sophomores who engaged in research projects were significantly less likely to leave STEM majors than those who did not.

Actions:

- Fund implementation of research courses for students in the first two years.
- Establish collaborations between research universities and small colleges to provide all students access to research experiences.

Freshman Research Initiative: University of Texas at Austin

The facts:

- > 600 freshmen per year.
- > 40% from underrepresented groups.
- > 70% still researching at the end of their third year.
- Over 20 unique research areas, including many that were not previously accessible for freshman

The Program:

- Students participate in authentic research from the start.
- FRI effectively opens up a faculty lab to 30 students
- Coursework is directly integrated with research
- They work on their own independent, hypothesis driven project, within the larger research question.
- Students publish in peer-reviewed journals and present at national conferences.
- Their data contributes to larger faculty research projects.

The Results:

- FRI students have higher GPAs and get more scholarships.
- They remain in scientific career paths and participate more fully in the scientific research community.

Source: http://fri.cns.utexas.edu/

Recommendation #2

Advocate and support replacing standard laboratory courses with discovery-based research courses.

Premise:

Students who engage in research early in college are more likely to persist in STEM majors.

Actions:

- Fund implementation of research courses for students in the first two years.
- The transition to research courses should be supported by the Federal government with accompanying funds raised by colleges and universities through private and philanthropic sources.
- Establish collaborations between research universities and small colleges to provide all students access to research experiences.

Recommendation #2

Advocate and support replacing standard laboratory courses with discovery-based research courses.

Premise:

Students who engage in research early in college are more likely to persist in STEM majors.

Actions:

- Fund implementation of research courses for students in the first two years.
- Establish collaborations between research universities and small colleges to provide all students access to research experiences.
- Federal support of undergraduate research opportunities should expand to encourage involvement of first and second year students
- Cross-institutional research opportunities should be encouraged and funded (to engage students at non-research and community colleges in authentic, world-class research)

Recommendation #3

Launch a national experiment in postsecondary mathematics education to address the math-preparation gap.

Premise:

College-level skills in mathematics and, increasingly, computation are a gateway to other STEM fields.

Nearly 60% of students enter college without the math skills needed for STEM majors.

This gap causes a large burden of cost and time on remediation

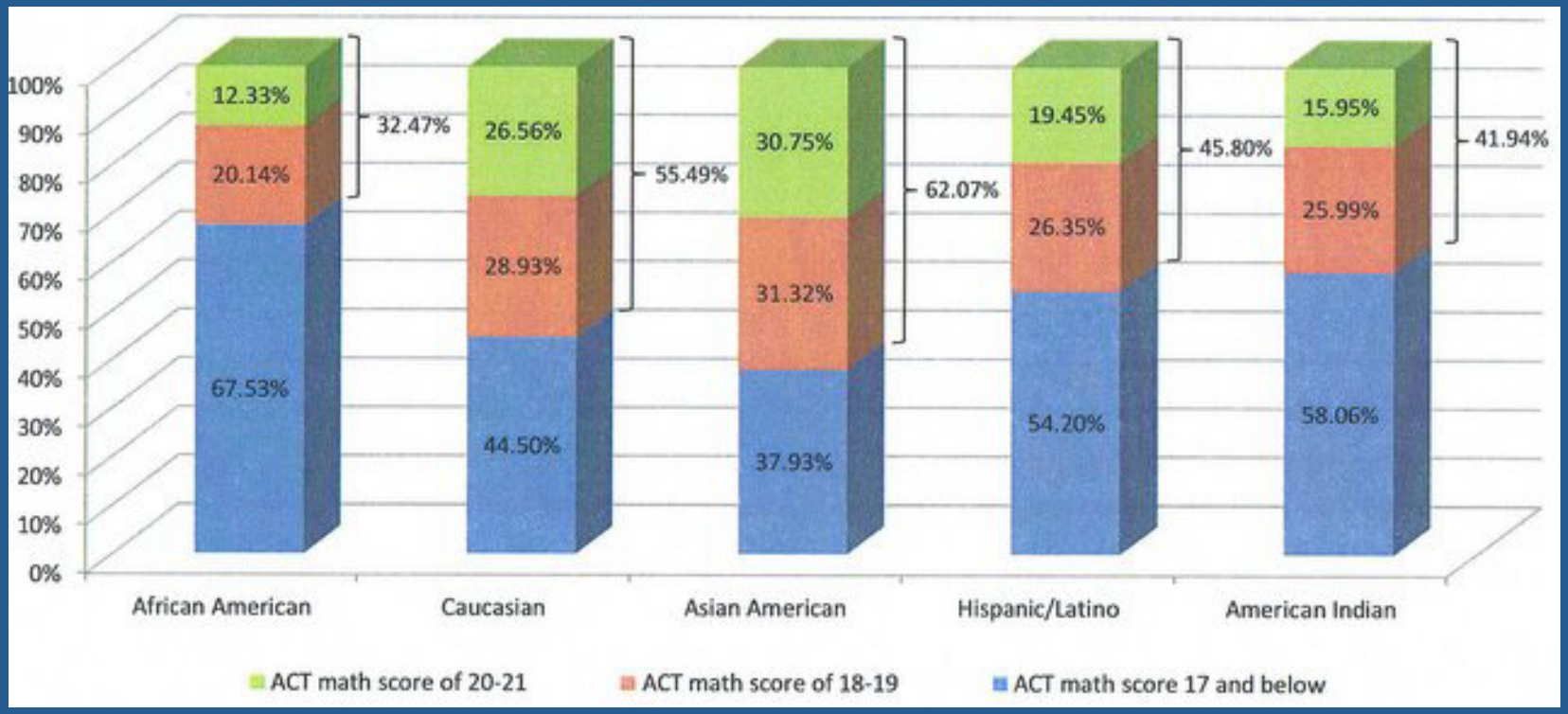
Actions:

- Support a national experiment in mathematics undergraduate education aimed at developing new approaches to remove the math bottleneck.
- Identify most successful strategies and replicate.

Evidence of a Math Preparation Gap-

Many Students are Not Far Below the Line

Figure E-2. High School Student Performance on ACT Math Exam

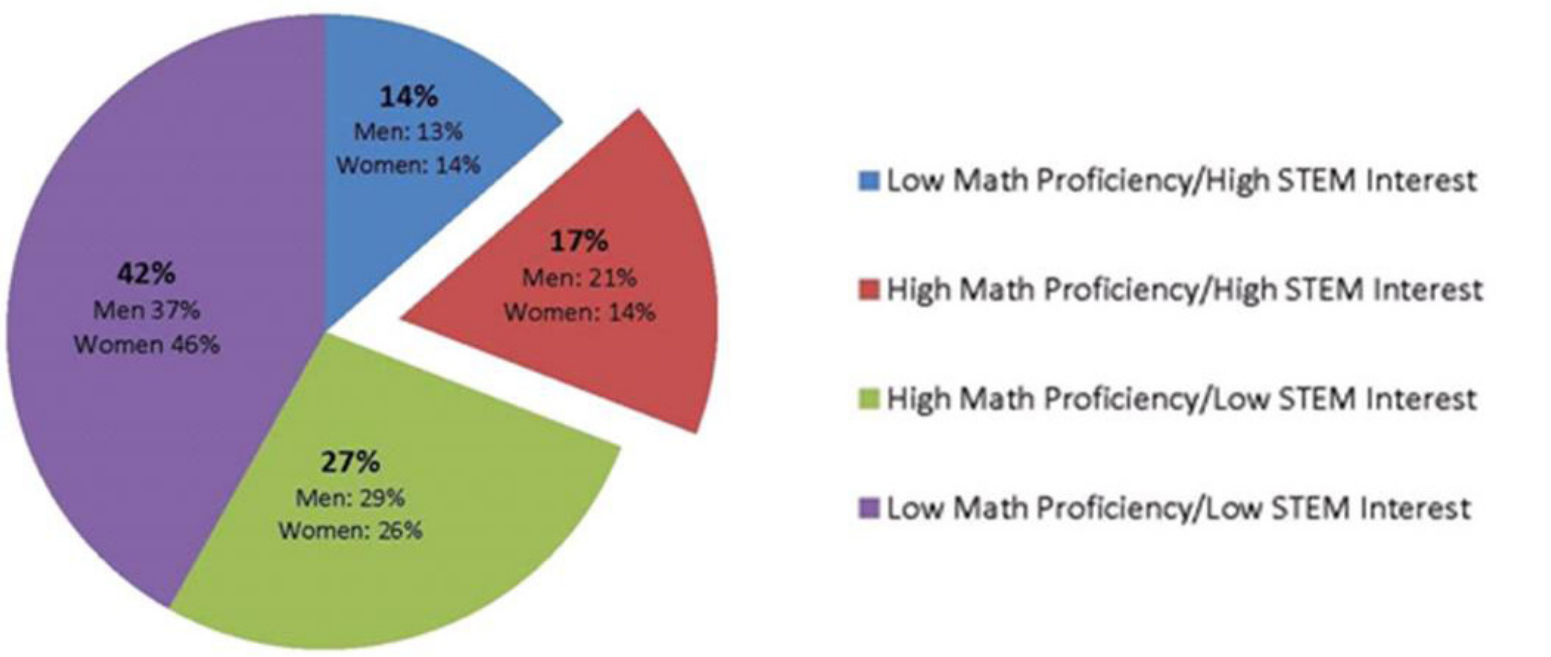


Source: ACT. (2011). *The Condition of College & Career Readiness 2011*. Iowa City, IA: ACT.

Note: Students who score a 22 or higher on the mathematics portion of the ACT exam are considered math proficient and have a high probability of college success.

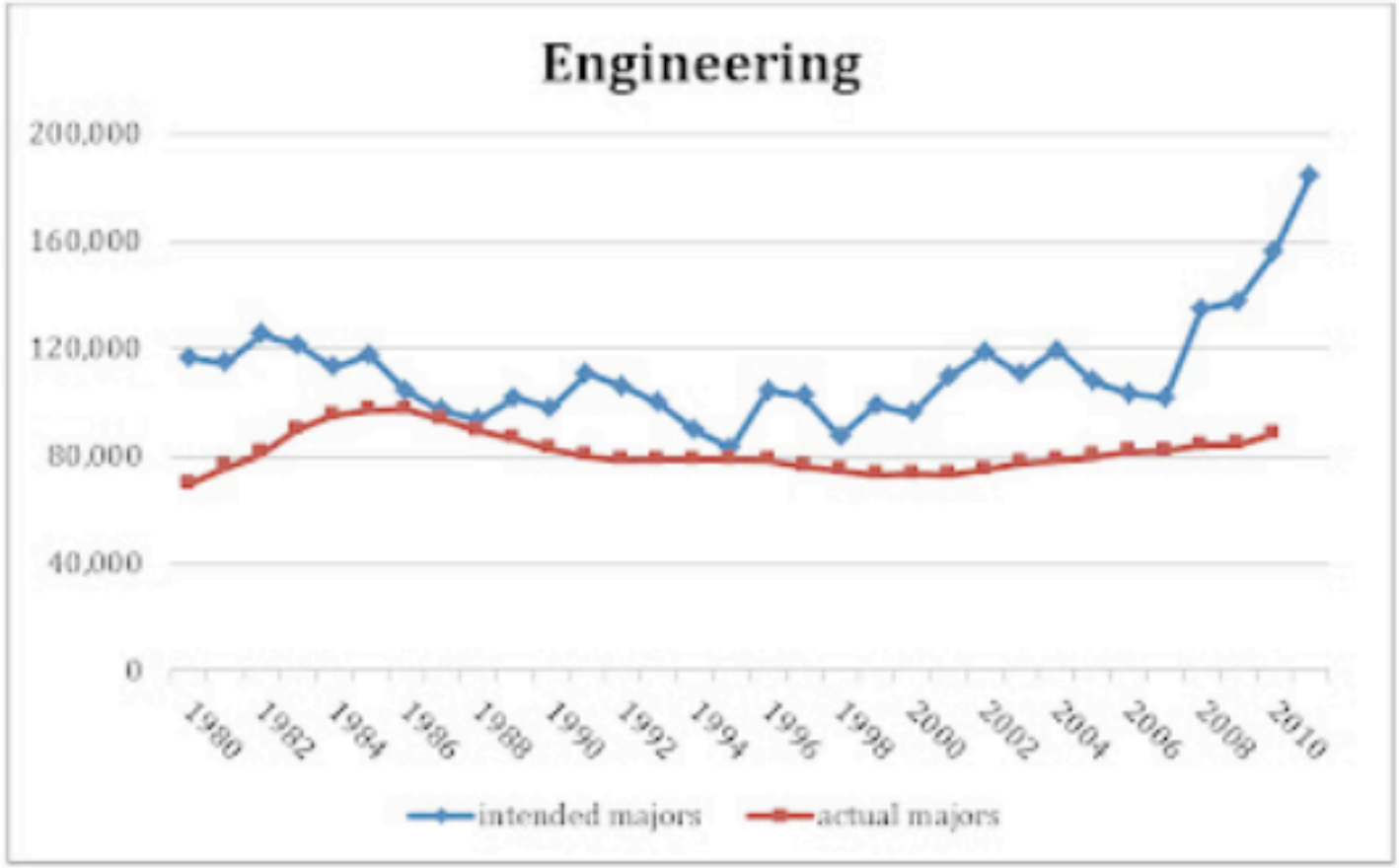
An Opportunity to Engage STEM-Interested Students

Figure E-1. 12th Grade Student STEM Interest and Mathematics Proficiency

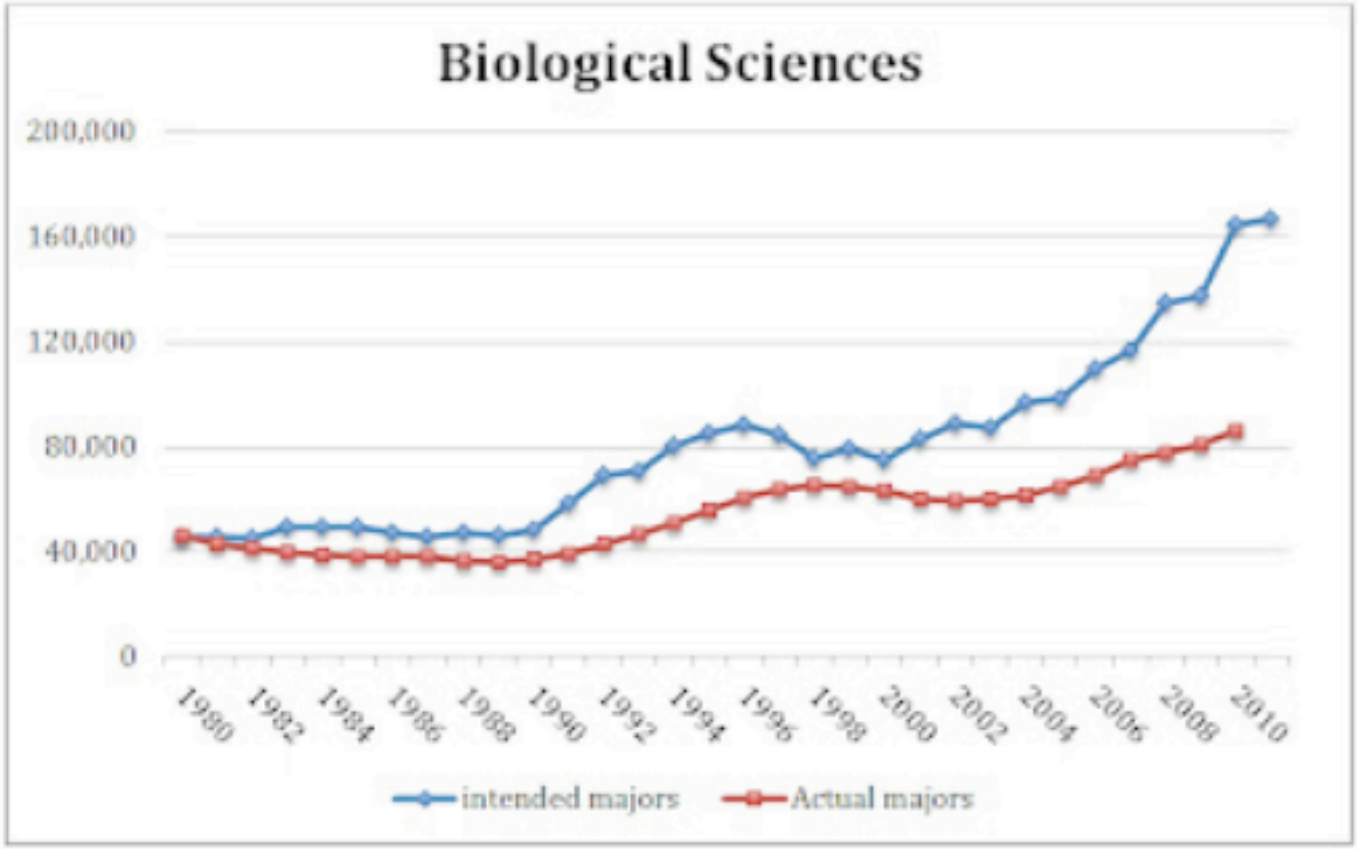


Source: The Business-Higher Education Forum. (2011). The STEM interest and proficiency challenge: Creating the workforce of the future. Washington, DC.

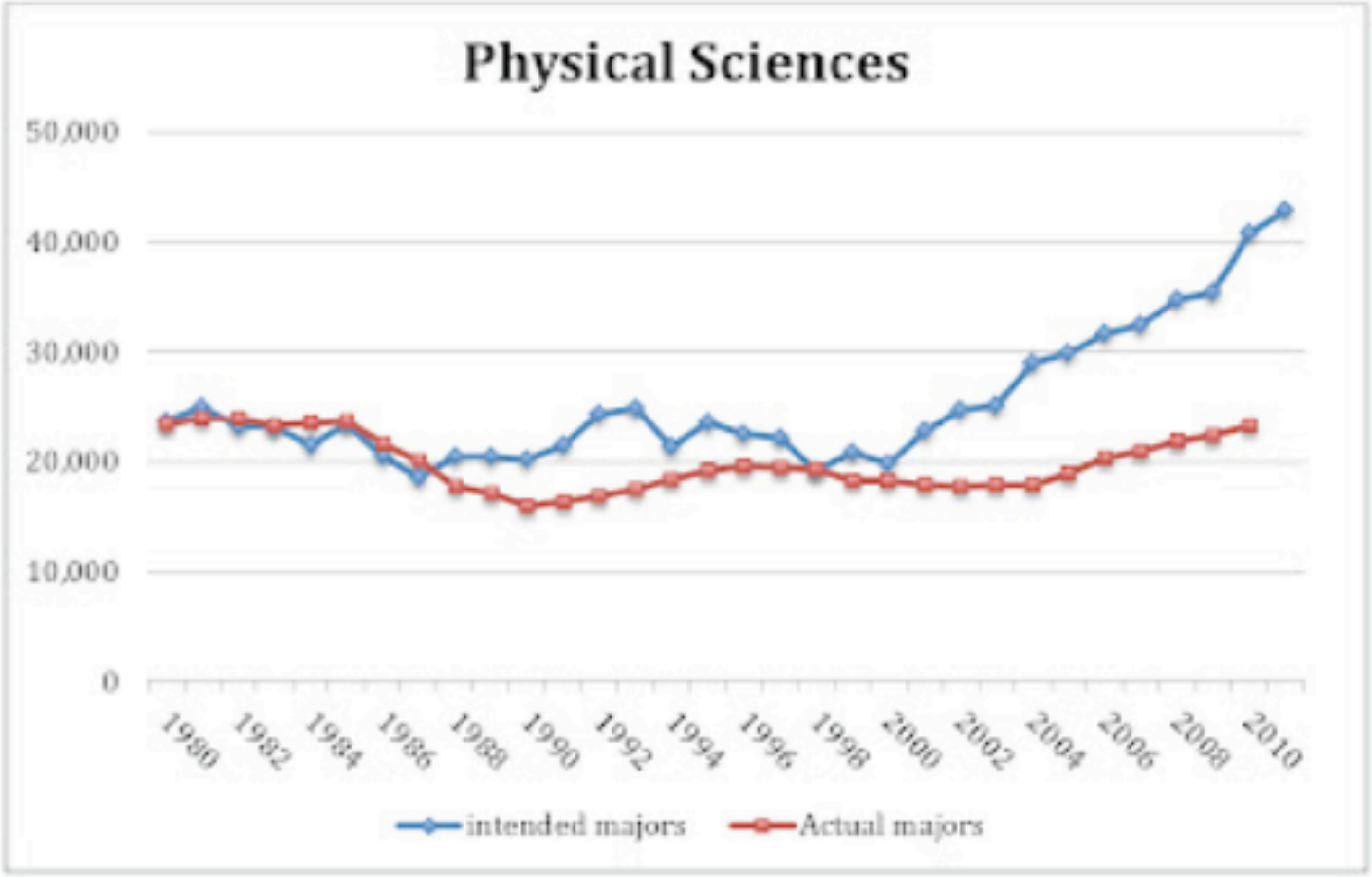
- About 14% of 12th graders are interested in STEM fields but not proficient in math.



Graph 1: Intended versus actual majors in Engineering
(includes engineering technologies).
All freshman data are from [1], all graduation data from [2].



Graph 2: Intended versus actual majors in the Biological Sciences.



Graph 3: Intended versus actual majors in the Physical Sciences.

Recommendation #3

Launch a national experiment in postsecondary mathematics education to address the math-preparation gap.

Actions:

- Support a national experiment in mathematics undergraduate education aimed at developing new approaches to remove the math bottleneck.

Including a variety of approaches not limited to:

(1) bridge programs for high school students entering college;

(2) remedial courses for students in college, including approaches that rely on computer technology;

(3) college mathematics teaching and curricula developed and taught by faculty from mathematics-intensive disciplines

(4) a new pipeline for producing K-12 mathematics teachers from undergraduate and graduate programs in mathematics-intensive fields other than mathematics.

Recommendation #3

Launch a national experiment in postsecondary mathematics education to address the math-preparation gap.

Premise:

College-level skills in mathematics and, increasingly, computation are a gateway to other STEM fields.

Nearly 60% of students enter college without the math skills needed for STEM majors.

This causes a large burden of cost and time on developmental math

Actions:

- Diverse institutions should be included in the experiment to assess the impact of interventions on various types of students and schools.
- Identify most successful strategies and replicate.

Recommendation #4

Encourage partnerships among stakeholders to diversify pathways to STEM careers.

Premise:

STEM education needs to accommodate the expanding pool of students, such as adults, working students, and those with atypical backgrounds, by providing multiple pathways rather than a "pipeline" to a STEM career.

Actions:

- Foster partnerships between 2-year and 4-year institutions, high schools and colleges.
- Encourage public-private partnerships to support STEM programs and provide hands-on research and internships experiences.

Partnerships for STEM Excellence

- Public and private entities should support summer bridge programs to prepare students for STEM coursework and inspire them to pursue STEM degrees.
- Scientific research and engineering design exchanges across 2-and 4-year institutions should be encouraged and supported to improve the STEM education of 2-year students and ease their potential transition to 4-year schools
- The Federal Government should engage private industry and foundations to support successful programs that create bridges between high schools and colleges and between 2-and 4-year institutions and ensure that programs incorporate learning standards and content consistent with industry-recognized skills.
- Data on STEM jobs and pathways should be improved to make visible the availability of STEM careers to the future workforce

Recommendation #5
Create a Presidential council on STEM education with broad leadership.

Premise:

Transformative and sustainable change requires leadership from industry, academia, and government.

Actions:

The council should include members that represent the breadth of academic institutions, professional societies, businesses, and private foundations involved in the development and use of human capital in STEM fields.

- Address structural barriers to change.
- Identify new resources to support STEM education.

Recommendation #5
Create a Presidential council on STEM education with broad leadership.

The council could provide a forum for leaders in the public and private sectors to:

- weigh in on the development and deployment of metrics to evaluate STEM departments (Recommendation 1),
- design collaborative coalitions to support initiatives in STEM education (Recommendation 4), including expanding internship programs in industry and connecting industrial research agendas with research courses (Recommendation 2),
- provide advice and review for the National Experiment in Math Undergraduate Education (Recommendation 3) and could conduct further study of the math education issue, if necessary.

Engage to Excel:

Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics

President's Council of Advisors on Science and Technology

http://www.whitehouse.gov/ostp/pcast

‘ ‘If we’re serious about building a stronger economy and making sure we succeed in the 21st century, then the single most important step we can take is to make sure that every young person gets the best education possible, because countries that out-educate us today are going to out-compete us tomorrow.’ ’

President Barack Obama,
September 2010