Consultant Report

Securing Australia's Future

STEM: Country Comparisons

This report can be found at www.acola.org.au

STEM Education in the United States

Adam V. Maltese, Indiana University - Bloomington
Florin D. Lung, Clemson University
Geoff Potvin, Clemson University
Craig D. Hochbein, University of Louisville

Table of contents

Introduction

To comprehend and learn from the development, implementation, and accomplishment of educational policies in the United States (US), it is important to understand the structure and dynamics of the educational system. Thus, we begin this report with an introduction to this system to provide the reader with sufficient background to make sense of the policies and issues discussed throughout this report. The focus here is predominantly on the K-12 system, as this is where the bulk of the policies, funding and educational research are focused. This is followed by a discussion of recent performance on national and international assessments by US students that provides some context for the current status of STEM and STEM education in America. We believe this background sets the stage for understanding the current status of STEM education in the US.

Part I. Public education in the United States

To gain a deeper understanding of education in the US, interested parties must consider the influences of two elements of the American educational system. First, the composition of the school and student populations demonstrates distinct differences with those from other countries[1]. Second, the operational control of local educational agencies (LEAs) and individual schools warrants consideration by students of American educational policies. Together these characteristics of the educational system distinguish the United States from many other countries, including those labeled as high-performing as measured by international assessments such as Trends in Mathematics and Science Study (TIMSS) and Program for International Student Assessment (PISA).

School and student population composition

Since Friedman[2] first suggested the use of private markets to increase student achievement and school performance in the United States, the role and number of non-public schools has increased. Despite the proliferation of charter schools and school voucher programs, public schools remain the dominant form of education in the United States. The National Center for Educational Statistics (NCES) released a report that estimated in the 1999-2000 school year public schools constituted 76% of the school population, while educating 90% of students and employing 88% of full time teachers[3]. Because the overwhelming majority of American students attend some form of public school, we focus here on describing the public education landscape.

Utilizing data from the 2010-2011 school year, researchers[4] identified the operation of 13,592 *regular school districts* that educated 48.1 million students in the US. In contrast, during the same year they found 2,359 *charter agencies* that educated 951,650 students. Although charter schools often receive substantial media and research

---

1 Sahlberg, P. (2011). Finish lessons: What can the world learn from educational change in Finland. New York, New York: Teachers College Press.

2 Friedman, M. (1955). 'The role of government in public education.' In R.A. Solo (ed.) *Economics and the Public Interest*. New Brunswick, NJ: University of Rutgers Press.

3 Alt, M.N. & Peter, K. (2002). *Private schools: A brief portrait*. Washington, DC: U.S. Department of Education, National Center for Education Statistics.

4 Keaton, P. (2012a). *Numbers and types of public elementary and secondary local education agencies from the Common Core of Data: School Year 2010–11* (NCES 2012-326rev). Washington, DC: U.S. Department of Education, National Center for Education Statistics.

attention, far more students attend public schools. Similarly, authors and scholars often focus on large districts, but only 26 *regular school districts* in the United States educated more than 100,000 students. Nearly 28% of *regular school districts* educated between 1,000 and 2,999 students, while 912 *regular school districts* (7%) operated with fewer than 100 students enroled. Given these district sizes, 12.3% of public school students attended a district with 100,000 or more students, whereas 45.7% of students enroled in districts with fewer than 10,000 students.

Regardless of school district type, it is estimated that 49.5 million students attended all forms of publicly-funded schools in the United States during 2010-2011[5]. Of those students who reported their ethnicity, 52% identified as White, 23% Hispanic, 16% Black, 5% Asian, 1% American Indian/Alaskan Native, with 2% identifying at 'Two or more races'.

The Free and Reduced Lunch (FRL) Program subsidizes the cost of school lunches for students whose families do not meet certain economic benchmarks related to levels of poverty. Students are eligible for reduced price meals if their family income is at or below 1.85 times the federal poverty levels (based on family size and location) and free meals if income is at 1.3 times the levels, which are established annually[6]. In 2009-2010[7], researchers at NCES calculated that 46% of the public school student population was deemed eligible to receive FRL in schools, a 12% increase since 1999-2000[8]. According to others[9], in 2009-2010, 37% of both Black and Hispanic students attended public schools with at least 76% of the student population eligible for FRL, whereas only 6% of white students attended similarly comprised schools.

Together these statistics demonstrate that the vast majority of students, regardless of ethnicity or economic condition, attend a public school. However, the large number of LEAs exhibit significant variability in the size and composition of schools. Slightly less than half of all public school students identified as a racial or ethnic minority and nearly half of all public students were eligible for the FRL program. However, the distribution of students across schools was not similar, with a greater percentage of minority students attending economically disadvantaged schools as compared to their White peers.

---

[5] Keaton, P. (2012b). *Public elementary and secondary school student enrolment and staff counts from the Common Core of Data: School Year 2010–11* (NCES 2012-327). Washington, DC: U.S. Department of Education, National Center for Education Statistics.

[6] Program specifics available here: http://www.fns.usda.gov/cnd/Governance/notices/iegs/IEGs.htm

[7] For a family of four to be eligible in 2009-2010, levels were set at $40,793 for reduced price meals and 28,665 for free meals.

[8] Data retrieved from here: http://nces.ed.gov/ccd/tables/2000_schoollunch_01.asp

[9] Aud, S., Hussar, W., Johnson, F., Kena, G., Roth, E., Manning, E., Wang, X., & Zhang, J. (2012). *The condition of education 2012* (NCES 2012-045). Washington, DC: U.S. Department of Education, National Center for Education Statistics.

Operational control of schools

Possibly to accommodate the heterogeneity in the size and composition of districts and schools, decentralization best characterizes the operational control of public education in the United States. The overwhelming majority of decisions about the creation and operation of districts and schools occurs at the local level. Although the United States Department of Education (DoEd) exists, the department was not formally established as part of the President's Cabinet until 1979. Furthermore, the role of the DoEd is unlike many of its counterparts from other countries. According to Section 103[b] of Public Law 96-88[10]:

> No provision of a program administered by the Secretary or by any other officer of the Department shall be construed to authorize the Secretary or any such officer to exercise any direction, supervision, or control over the curriculum, program of instruction, administration, or personnel of any educational institution, school, or school system, over any accrediting agency or association, or over the selection or content of library resources, textbooks, or other instructional materials by any educational institution or school system, except to the extent authorized by law.

The sentiment of decentralized control of public education is supported by both the selection of educational leaders and funding of education.

The organizational hierarchy of the typical public school consists of teachers who report to a building-level principal, with some variation in the number and responsibilities of mid-level administrators within each building. In most cases these building-level principals were selected by district-level superintendents. These superintendents were selected by school board members who were elected by the citizens of a given region. However, wide variation exists in the selection processes, the regional boundaries, and even the responsibilities of individuals at the district, regional and state levels.

For example, a single individual who is appointed by the mayor of the city leads the New York City School District enroling more than one million students annually. In contrast, the mayor of Baltimore, Maryland appoints a school board and gives those individuals the responsibility of selecting, rewarding, and sanctioning the Superintendent of Baltimore City Public Schools. Further complicating the leadership and operational control of schools are state superintendents of instruction. Again, variation in the selection and responsibility of these individuals exists. For instance, in the most recent elections (November 2012) the incumbent Superintendent of Instruction for the state of Indiana lost his bid for reelection, but within a few weeks he applied for and was appointed by the Governor of Florida to the same post in that state.

The decentralized operational control of schools is further supported by the sources of funding. Although the federal government contributed $56.7 billion to the educational revenues of the 50 states and the District of Columbia in fiscal year 2009, this amount only constituted approximately 10% of the $593.1 billion revenues of these entities[11]. State and local sources accounted for 46.7% and 43.7% of these revenues, respectively.

[10] Quoted from: http://uscode.house.gov/download/pls/20C48.txt

[11] Johnson, F., Zhou, L., & Nakamoto, N. (2011). *Revenues and expenditures for public elementary and secondary education: School Year 2008–09 (Fiscal Year 2009)* (NCES 2011-329). Washington, DC: U.S. Department of Education, National Center for Education Statistics.

Variation across the states in expenditures per pupil further demonstrates the decentralized nature of the American system. In 2009, the mean expenditure per pupil in the United States was $10,951, whereas Connecticut was $15,353 and the District of Columbia was $19,698, Utah ($6,612) was considerably lower[5]. While the ratio of funding sources above is slightly different from the funding for 2010, where the federal commitment was substantially greater ($74 billion)[12], much of that difference is attributed to a package of federal funding meant to stimulate the economy. Despite this, the overall amount of funding ($593.7 in 2010) and average amount spent per pupil ($10,615 in 2010) changes little from year to year.

As mentioned, decentralized and localized control characterizes the operation of public education in the United States. Although the operational control of schools follows a fairly predictable template, local nuances in the selection of leaders and funding of districts and schools leads to wide variation in the daily operation of schools. Practices such as training, selecting, and rewarding classroom teachers vary from locale to locale. Furthermore, the selection of the curricula and the resources to support it also vary across regions, states, and even municipalities.

This loose coupling, or decentralized control, of school systems means that it is impossible for the federal government to mandate educational practices. In practice this means that there is no national curriculum, no established standard for school inspections, and no high stakes testing at the end of schooling to determine university or employment status. One educational historian puts this in context stating, 'As a loosely coupled system, the American school system is a terrible medium for transmitting reform, but at the same time, it's a bulwark against the spread of harmful approaches to teaching and learning'.[13] Thus, this situation can be considered both a strength and a difficulty, as it reduces the likelihood of systemic failure, but it also increases the difficulty of implementing wide-ranging reforms, including current ones focused on improving STEM education. Below we present information related to one of the most recent reform efforts advanced by the federal government and discuss its influences on the educational system.

No Child Left Behind

Without question, the largest legislative influence on education during the last decade has been the No Child Left Behind Act of 2001[14] (NCLB; formerly the Elementary and Secondary Education Act of 1965) signed into law by President George Bush. Despite the decentralized nature of the public education system in the United States, NCLB established a national accountability system that wields considerable influence over public schools[15]. Prior to the implementation of NCLB, school accountability systems existed in several states[16,17,18]. Yet, works describing the disparities and inequalities

12 U.S. Census Bureau. (2012). Public Education Finances, 2010. Washington, DC: U.S. Census Bureau. Retrieved from: http://www2.census.gov/govs/school/10f33pub.pdf

13 Labaree, D.F. (2010). Someone has to fail: The zero-sum game of public schooling. Cambridge, MA: Harvard University Press. p. 132.

14 Full text available here: http://www2.ed.gov/policy/elsec/leg/esea02/index.html

15 Stringfield, S. C., & Yakimowski-Srebnick, M. E. (2005). Promise, progress, problems, and paradoxes of the three phases of accountability: A longitudinal case study of the Baltimore City Public Schools. *American Educational Research Journal, 42*(1), 43-75. doi: 10.3102/00028312042001043

16 Hess Jr., G. A. (1999). Expectations, opportunity, capacity, and will: The four essential components of Chicago School Reform. *Educational Policy, 13*(4), 494-517.

experienced by minority and disadvantaged children in American schools highlighted the need to hold schools responsible for educating all children[19,20,21]. Assuming that public reporting of school performance would spur improvement in student achievement and reduce inequalities, advocates lobbied for a national school accountability system.

The policy architects of NCLB required schools receiving federal funding to test all students in the areas of literacy and mathematics and publicly report the performance of the school. The law also required that school officials disaggregate and report student performance by mandated groups, such as ethnicity, sex, and FRL status. Each year schools needed to demonstrate sufficient performance or improvement in a given area, known as adequate yearly progress (AYP), with the ultimate goal of 100% student proficiency in literacy and mathematics by 2014. Schools that failed to reach predetermined AYP benchmarks faced an increasing slate of sanctions, such as allowing student transfers, take-over by the state, or even closure. The reason this is important is that performance on state designed standardized tests drives much of what schools do, especially those at risk of not meeting AYP, over the next decade.

While NCLB allowed science to be part of each state's AYP calculus, given that it was not a required element, it was relegated to secondary status and there was commonly discussion of how science – and other non-tested subjects – was subjected to the narrowing of the curriculum, where class time was reallocated to spend more time on instruction and practice examinations for tested subjects (i.e., English, mathematics)[22].

Although NCLB was a federal policy, wide variation existed in the implementation of the law. For instance, each state maintains the authority to determine the content and form of the required literacy and mathematics test, rendering comparison between states virtually impossible. In addition, leaders at state departments of education were able to determine not only their own annual proficiency benchmarks, but also the minimum number of students required to constitute a required NCLB group report. Such variances have compelled critics to question the validity, reliability, and utility of NCLB[23,24,25,26]. Other researchers have also challenged the ability of the law to improve school performance[27] or student achievement[28,29,30].

---

17 Spillane, J. P., Diamond, J. B., Walker, L. J., Halverson, R., & Jita, L. (2001). Urban school leadership for elementary science instruction: Identifying and activating resources in an undervalued school subject. *Journal of Research in Science Teaching, 38*(8), 918-940.

18 Wolf, S. A., Borko, H., Elliot, R. L., & McIver, M. (2000). 'That dog won't hunt': Exemplary school change efforts within Kentucky reform. *American Education Research Journal, 37*(2), 349-393. doi: 10.3102/00028312037002349

19 Kotlowitz, A. (1991). *There are no children here: The story of two boys growing up in the other America.* New York, NY: Random House, Inc.

20 Kozol, J. (1991). *Savage inequalities: Children in America's schools*. New York, NY: Crown.

21 Suskind, R. (1998). *A hope in the unseen: An American odyssey from the inner city to the Ivy League.* New York, NY: Broadway Books.

22 National Science Teachers Association. (Summer 2011). Elementary teachers getting less time for science. NSTA Reports, p. 17.

23 Forte, E. (2010). Examining the assumptions underlying the NCLB federal accountability policy on school improvement. *Educational Psychologist 45*(2), 76-88. doi: 10.1080/00461521003704738

24 Hoxby, C. M. (2005). Inadequate yearly progress. *Education Next*, 5(3), 46-51.

25 Kane, T. J. & Staiger, D. O. (2002). The promise and pitfalls of using imprecise school accountability measures. *The Journal of Economic Perspectives, 16*(4), 91-114.

26 Peterson, P. E. & West, M. R. (2006). Is your child's school effective: Don't rely on NCLB to tell you. *Education Next, 6*(4), p. 76-80.

27 Stuit, D. A. (2010). *Are bad schools immortal? The scarcity of turnaround and shutdowns in both charter and district sectors.* Washington, D. C.: Thomas B. Fordham Institute.

28 Choi, K. Seltzer, M. Herman, J. & Yamashiro, K. (2007). Children left behind in AYP and non-AYP schools: Using student progress and the distribution of student gains to validate AYP. *Educational Measurement: Issues and Practice, 26*(3), p. 21-32.

29 Hemelt, S. W. (2011). *Economics of Education Review.* DOI: 10.1016/j.econedurev.2011.02.009

30 Maltese, A. & Hochbein, C. (2012). *Journal of Research in Science Teaching*. DOI: 10.1002/tea.21027

As we near the initial deadline set by the NCLB legislation (2014), the initiative has essentially lost its teeth as failure to meet goals has resulted in permission of waivers, further instantiating the decentralization of educational control. The Obama Administration has allowed for 'flexibility' and set up a system where states can apply for waivers from meeting NCLB targets. To date, 44 states have applied for waivers and 34 have been granted waivers[31].

Whether or not NCLB was successful in raising school performance and improving student achievement, leaders at the DoEd continued to utilize its policy blueprint in attempts to implement national policies. Unable to mandate policies at the state, district, or school levels, leaders at the DoEd have established requirements for eligibility for federal funding. For instance, the Obama Administration's Race to the Top grant competition utilized a detailed rubric to judge state applications for more than $4 billion in funding from the DoEd. Although these rubric items did not establish federal policies, grant applications from states without sufficient laws to support charter schools, mechanisms to judge teacher performance, or procedures to improve persistently low-achieving schools received lower marks on the rubric. Similarly, DoEd guidelines for the Title I School Improvement Grants required districts to implement one of the four school turnaround methods prescribed the DoEd. By establishing such prerequisites for funding, leaders at the DoEd have been able to influence school, district, and state policies without the formal means to establish and enforce national policies.

Part II. Student achievement in mathematics and science

Much of the recent focus on STEM education in the US is at least partially rooted in the performance of US students on national and international assessments. To understand this pretext, in the next few sections we discuss the performance of American students, first in the context of national assessments and then on international assessments[32]. Where appropriate, comparisons are made to Australian students[33].

National Assessment of Educational Progress

The National Assessment of Educational Progress (NAEP), which is known as *The Nation's Report Card*, is conducted every year on a nationally representative sample of 4th, 8th and 12th grade students in nearly every state in the US. Each year the focus of the NAEP exams alternate between a wide range of content areas and include a mix of items across complexity levels. In math[34], items are included to assess performance in the following content domains: number properties, measurement, geometry, data analysis/probability and algebra. In science[35], the assessments evaluate students across the science disciplines and common scientific practices. The proportion of items for the different math and science content areas varies based on grade levels. Table I.1 presents the item coverage for 8th grade exams in math and science for 2011.

[31] Information available here: http://www2.ed.gov/policy/elsec/guid/esea-flexibility/index.html
[32] Unless otherwise noted, all data related to student performance was retrieved from online database tools accessible at http://nces.ed.gov
[33] Throughout the report we do not include measures of significance for comparisons due to lack of complete information that would allow for robust calculation of these values across all included measures.
[34] http://nces.ed.gov/nationsreportcard/mathematics/distributequest.asp
[35] http://nces.ed.gov/nationsreportcard/science/distributequest.asp

There are two different forms of NAEP used. The main NAEP assessments are now given every year and are updated regularly to keep pace with current standards and curricula, as well as assessment methods. Direct comparison of scores from year to year on the main NAEP exams likely involves different items and formats. Math and reading are assessed every two years, with other subjects (e.g., science) included less frequently. The Long-Term Trend version of NAEP is meant to provide a stable assessment tool for longitudinal comparisons of student performance in mathematics and reading, and has changed little since the original administration in the early 1970s. The Long-Term Trend assessments are administered every four years to students at ages 9, 13, and 17 instead of the grade level samples for main NAEP.

Table I.1. NAEP 2011 item coverage for 8th grade assessments in mathematics and science.

Mathematics		**Science**			
Content Area	*Coverage*	*Content Area*	*Coverage*	*Scientific Practice*	*Coverage*
Number properties and operations	17	Physical Science	26	Identifying science principles	24
Measurement	17	Life Science	33	Using science principles	37
Geometry	19	Earth & Space Sciences	41	Using scientific inquiry	28
Data analysis, statistics & probability	15			Using technological design	10
Algebra	32				

Using the Long-Term Trend data, it is possible to look at the trend in math scores going back to the late 1970s, with assessment points every few years (Figure I.1). For 17 year olds, there has been little change in their performance over that time period, with a persistent gap of a few points between the performance of males and females. For 13 year olds, there was a 15-20 point increase in performance over this same time period, but with a growing gap in performance between genders. The youngest students, 9 year olds, showed the greatest gains of nearly 25 points from 1978-2008. For this age group, there is generally no performance difference between genders.

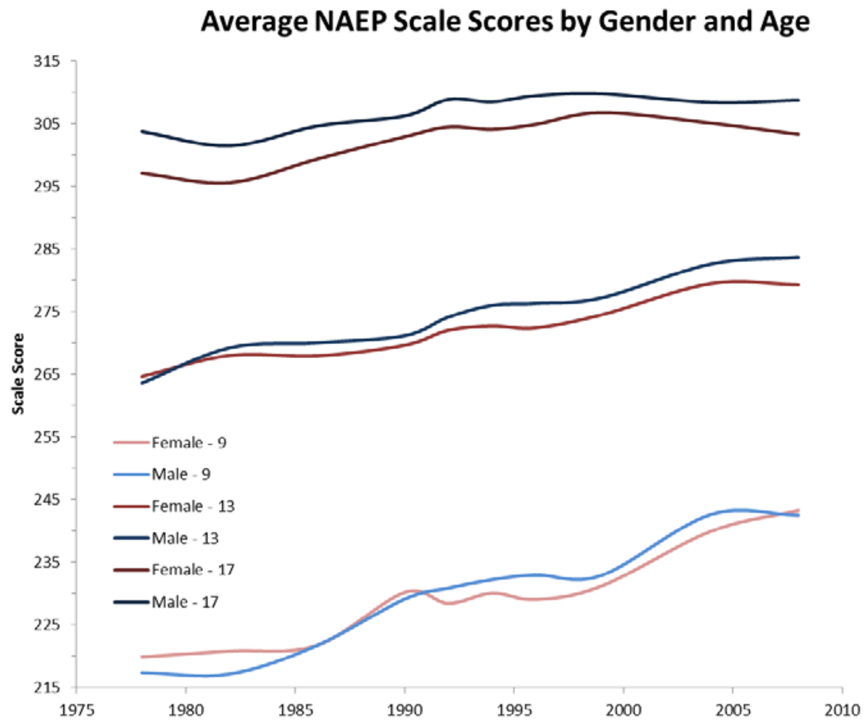


Figure I.1. Long-Term Trend Mathematics scores for 1978-2008, by gender and age. Scale range is from 0 to 500 for each age assessed.

There are no comparable long-term data for NAEP Science, but it is possible to look at trends in scores going back to 1996 for grades 4, 8 and 12. It is important to note that the NAEP tests were redesigned/scaled using a new framework in 2009 and thus direct comparison of performance before 2009 with that in 2009 and 2011 is not possible.

Overall, the results indicate that there has been little change in performance level for students at each grade level across the years. While some of the changes across time are statistically significant (e.g., gain for 4th graders, decline for 12th graders) from 1996 to 2005, the small changes at the national level do not seem to be substantively significant. These scores are also evaluated in terms of proficiency levels (e.g., Basic, Proficient, and Advanced) to measure if students are near, at or above grade-level in their performance. Across all administrations, approximately 30% of students in 4th and 8th grade earn a rank of Proficient, while the percentage drops to near 20% for 12th graders.

Table I.2 also presents the scale scores for groups by gender and race/ethnicity. There is a consistent gap of 2-7 points between males and females across all grade levels with males attaining higher scores. Averaging these gaps for each grade does indicate that the gap increases from 2.6 points in 4th grade to 4.2 points in 8th grade to 4.6 points in 12th grade. When looking across racial/ethnic groups, there are persistent and substantial gaps in performance recorded in the data. White students generally perform above all other groups at each grade level. Using 12th grade data for comparison, the average difference in scores is smallest between White students and Asian/Pacific Islander students (4 pts), next is with American Indian/Alaska Native students (12 pts), followed by Hispanic (26 pts) and Black (34 pts) students. The gap between Black and White students is close to one standard deviation difference. In looking at this breakdown across grades, results indicate that the gap generally decreases as grade level increases.

Trends in International Mathematics and Science Study

Beyond the mixed performance of students on national exams, the performance of US students on international assessments is always a top news story when results are released. The Trends in International Mathematics and Science Study (TIMSS) provides the chance to compare the performance and attitudes of students across countries in math and science. TIMSS is administered every four years to students around the world who are in the equivalent of 4th and 8th Grades. In 2011 in the US, the average age of students taking the test was 10.2 years old for 4th grade and 14.2 years old for 8th grade[36]. By comparison, Australian students were slightly younger on average at 10 years old (Year 4) and 14 years old (Year 8), respectively. The focus of the TIMSS assessments is different for each of the grades assessed and subject. In math, the major content difference is the inclusion of Algebra in 8th grade[37]. In terms of cognitive domains (i.e., the types of questions asked) assessed, 8th grade students are faced with items that assess knowing (35%), applying (40%) and reasoning (25%). The difference in 4th grade is the inclusion of a few more items on knowing and a few involving reasoning. In science[38] the changes are more significant. In 4th grade the content coverage is divided between life science (45%), physical science (35%) and earth science (20%), while in 8th grade the division is: biology (35%), chemistry (20%), physics (25%) and earth science (20%). In terms of cognitive domains, there is equal focus on knowing (40%) and applying (40%), with less on reasoning (20%) in 4th grade. In 8th grade there is a 10% increase in items related to reasoning (30%), with equal reductions in knowing and applying as a result.

[36] Data retrieved from: http://timssandpirls.bc.edu/timss2011/downloads/T11_IR_M_AppendixC.pdf
[37] Data retrieved from: http://timssandpirls.bc.edu/timss2011/downloads/TIMSS2011_Frameworks-Chapter1.pdf
[38] Data retrieved from: http://timssandpirls.bc.edu/timss2011/downloads/TIMSS2011_Frameworks-Chapter2.pdf

Table I.2. Mean NAEP Science Scale Scores for American students (1996-2011), by grade, gender and race/ethnicity.

		All Students		Male		Female		White		Black		Hispanic		Asian/Pacific Islander		American Indian/Alaska Native	
	Year	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Grade 4	2009	150	35	151	36	149	34	163	29	127	32	131	34	160	35	135	34
	2005	151	31	153	32	149	30	162	26	129	29	133	30	158	30	138	30
	2000	147	36	149	36	145	35	159	30	122	32	122	35	‡	‡	135	38
	1996	147	35	148	36	146	34	158	30	120	31	124	35	144	36	129	39
Grade 8	2011	152	34	154	35	149	33	163	29	129	33	137	34	159	34	141	33
	2009	150	35	152	36	148	34	162	29	126	33	132	35	160	34	137	33
	2005	149	35	150	36	147	34	160	30	124	32	129	34	156	35	128	35
	2000	149	36	153	37	146	35	161	31	121	32	127	34	153	37	147	38
	1996	149	35	150	36	148	33	159	30	121	30	128	35	151	37	148	30
Grade 12	2009	150	35	153	36	147	34	159	31	125	32	134	33	164	37	144	33
	2005	147	34	149	35	145	33	156	30	120	30	128	32	153	32	139	36
	2000	146	34	148	35	145	33	153	32	122	30	128	32	149	38	151	28
	1996	150	33	154	34	147	32	159	30	123	30	131	31	147	36	144	27

Table I.3. TIMSS Mathematics and Science scale scores for 1995-2011, by country and grade.

		United States		Australia	
	Year	Grade 4	Grade 8	Grade 4	Grade 8
Math					
	1995	518	492	495	509
	1999		502		
	2003	518	504	499	505
	2007	529	508	516	496
	2011	541	509	516	505
Science					
	1995	542	513	521	514
	1999		515		
	2003	536	527	521	527
	2007	539	520	527	515
	2011	544	525	516	519

On the TIMSS assessments, there is some evidence for moderate gains for US students in math and in science from 1995-2011 (Table I.3). In math, American students demonstrated gains equaling 23 points for 4^{th} graders and 17 points for 8^{th} graders. By comparison, Australian 4^{th} graders saw gains of 21 points and 8^{th} graders a small decline of 4 points during these same periods. Interestingly, Australian 4^{th} graders ended up at the performance level where American 4^{th} graders started, while American 8^{th} graders ended where Australian 8^{th} graders began.

In science, American 4^{th} graders showed no substantive change in scores from 1995-2011, while 8^{th} graders manifested a gain of 12 points during this period. The results for Australian students were mixed, with 4^{th} graders showing overall a small decline from beginning to end (despite an uptick in 2007). Australian 8^{th} graders showed gains in each year of testing after 1995, but in 2011 achieved only a five point gain from their starting level in 1995.

Program for International Student Assessment

The Program for International Student Assessment (PISA) results offer another point of comparison across countries and time. PISA, coordinated by the Organization for Economic Cooperation and Development (OECD), has a different focus and as a result uses a different sample than TIMSS. Every few years PISA tests an international sample of 15 year olds in math, science and reading. The main content focus of PISA alternates between subjects for each administration – science was the focus in 2006, math in 2012 - but students are tested in each subject each year. These tests are generally considered to be different than NAEP or TIMSS as they center more on application of knowledge and reasoning than on factual recall. While students in different countries may be at varying stages in their educational careers at age 15, the reason for selecting this age is that it is close to the age at which most countries end mandatory schooling.

The results for PISA Math and Science tests demonstrate that since 2000 American students score at or below the average scale score for OECD countries on nearly every test (Figure I.2). In mathematics, the US had three rounds of declining scores followed by a slight improvement in 2009. By comparison, Australian students manifested a steady decline over this period, but consistently scored 30-40 points higher than American students.

In science, American students showed the same pattern as in math, with three rounds of declining scores followed by a performance in 2009 that was a few points better than their original score. Over this same period, Australian students demonstrated sustained performance and consistently scored higher than American students, by a margin of 25-38 points.

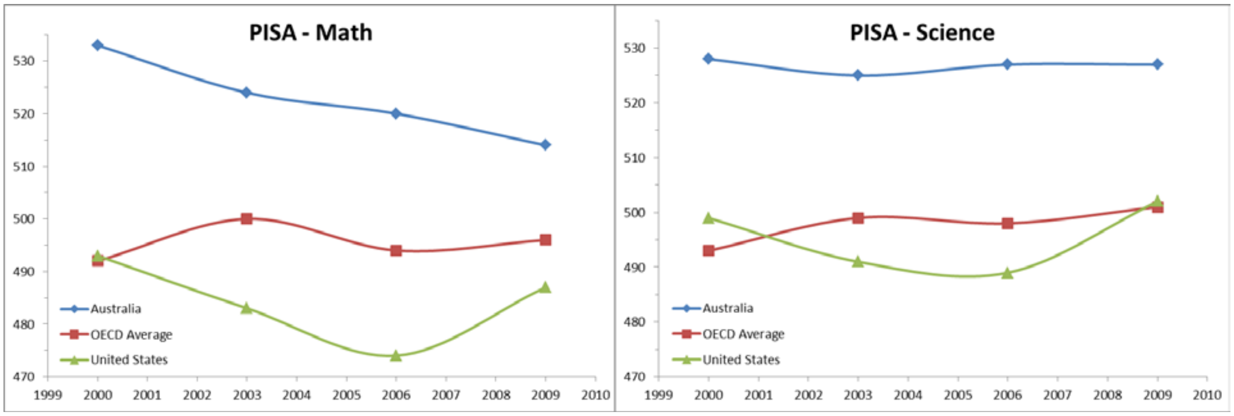


Figure I.2. PISA Mathematics and Science scale scores from 2000-2009, for the US, Australia and the OECD average score.

Digging a bit deeper into these numbers, it turns out that these national averages mask some interesting within- and between-country comparisons for both genders (Table I.4). As discussed above, for each test, Australian students scored above Americans, regardless of gender. In math, scores for American males and females followed the same trend as the national average, but the gap between the genders – with male students outscoring females - increased from 2000 (7 points) to 2009 (20 points) with an average difference of 11 points. There was a similar difference for Australian students with an average gap of 10 points, and both genders showing declines of about 20 points over this period.

In science, the story is a bit different. American females scored above males in 2000 by a difference of five points, scored five points below males in 2003, were equal in 2005 and finished 14 points behind males in 2009. By comparison, Australian females scored the same as or a few points above their male peers in each round of testing.

While many scholars express concerns over the validity of making such comparisons across nations with vastly varying political and educational systems, and economic stability[39], it is precisely these comparisons that media outlets and politicians use to grab the attention of the American public. Thus, when the performance of American students declines or when achievement scores are anywhere below the top few countries, as they have been for a while, the rhetoric intensifies about America's global position slipping. These comparisons have led to a form of envy where there is often discussion, and sometimes serious study[40], about how we can change what is done in American schools to be more like Finland or Singapore.

Table I.4. Mean PISA Mathematics and Science scale scores for 2000-2009, by country and gender.

[39] There has been some recent, unresolved criticism of how effectively the PISA sampling methodology was applied in the US. See http://www.epi.org/publication/us-student-performance-testing/.

[40] Sahlberg, P. (2011). Finish lessons: What can the world learn from educational change in Finland. New York, New York: Teachers College Press.

	United States				Australia			
	Female		Male		Female		Male	
Year	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
Math								
2000	490	94	497	103	527	88	539	91
2003	480	91	486	99	522	91	527	99
2006	470	88	479	91	513	84	527	91
2009	477	89	497	91	509	91	519	97
Science								
2000	502	95	497	107	529	91	526	97
2003	489	98	494	105	525	97	525	107
2006	489	102	489	110	527	96	527	104
2009	495	96	509	99	528	96	527	106

In an effort to graphically depict various elements of the international comparisons that are commonly made, Figure I.3 plots the PISA 2009 Science performance of countries versus the gross domestic product (purchasing power parity in US$) of those countries. For a number of countries that did not participate in PISA, but did participate in TIMSS 2007, a test score was imputed based on calculating concordance values for their TIMSS 2007 performance. Additionally, the youth population and the dominant (or official) language of each country are included for comparison. Despite the fact that the US ranks close to the top in both GDP and youth population, the fact that student performance is behind many Asian countries and on par with most of Europe is often characterized as troubling.

In summary, the performance of American students on national and international assessments of mathematics and science has been mixed. On NAEP Math, which provides the longest record of performance (1978-2008), students demonstrated gains with the youngest students (age 9) showing the greatest improvements, followed by 13-year-olds with moderate gains and 17-year-olds with minimal gains. Student performance on the TIMSS Math (1995-2011) assessments matches these results with gains for both 4th and 8th graders and larger gains for the younger students. On PISA Math (2000-2009), American 15 year olds showed no substantive change in scores, which generally matches the NAEP performance of 17-year-olds over this same period.

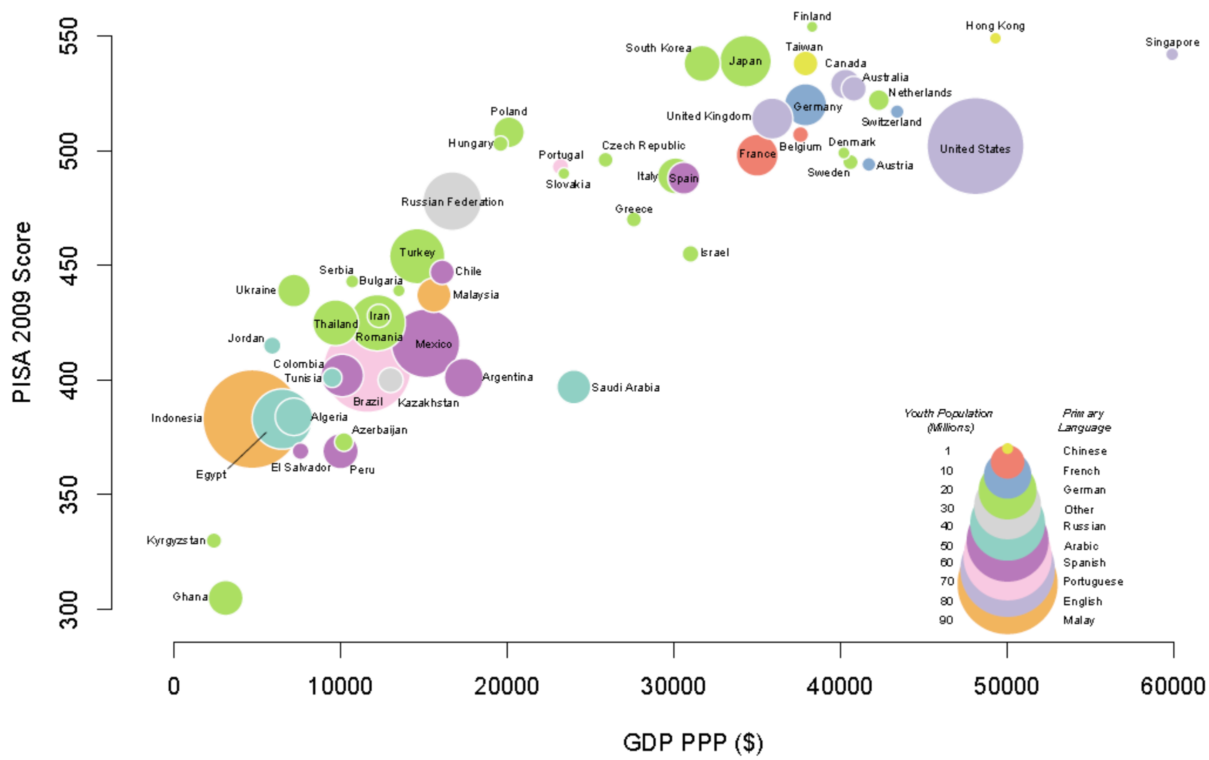


Figure I.3. Plot of PISA 2009 exam scores by GDP purchasing power parity and scaled by each country's youth population (Age 5-24). Different colors represent the most common language spoken in each country, colors have no association with population size. Only countries with populations of 5M or greater and that participated in PISA 2009 and/or TIMSS 2007 assessments are included. For those countries that did not participate in PISA 2009, a score was imputed using their performance on TIMSS 2007 and based on concordance values from countries that participated in both exams.

In terms of science performance, NAEP Science results suggest no substantial change in performance for students in grades 4, 8 and 12 since 1996, with the large majority of students (>65%) at each great level coming in below a level of *Proficient* on these exams. On TIMSS Science, American 4th graders showed no real change in scores over time, but 8th graders manifested a 12 point gain from 1995-2011. On PISA Science, scores for American students declined over three rounds, but finished up slightly (+3 points) in 2009 from their original level.

Beyond looking at longitudinal change in student performance, the international assessments offer the chance to compare students across educational systems. Again, the results offer mixed signals. On TIMSS, American 4th graders consistently outperformed Australian Year 4 students, while 8th graders bested their Australian peers only on the two most recent assessments. On PISA, in both math and science, American students consistently performed near the average mark for all OECD countries and well below their peers from Australia.

Terminology/glossary

Here we define key terms that are used throughout the report to provide readers with an understanding of the meaning we associate with these terms. In some places here and throughout the report, we note exceptional differences in definitions that are noteworthy. This issue is particularly important when it comes to defining what disciplines are in/out of STEM as the definition of disciplines can change the results and interpretation of findings[41].

Gender: Consistent with widespread practice within federal funding agencies and governmental reports, we will use the terms 'male' and 'female' as mutually exclusive terms to represent gender in this discussion. We recognize that this is a necessarily limited approach (and the terms 'male' and 'female' would normally be used to identify sex not gender) but in order to be consistent with existing data and reports, this is the terminology used here.

Race & Ethnicity: Again consistent with the U.S. Census and widespread usage in federal agency reporting, we will use the following mutually-exclusive terms to represent race: 'White', 'Black or African-American', 'American Indian/Alaskan Native', 'Asian', 'Native Hawaiian/Pacific Islander', 'Other', and 'Two or more races'. Note that Hispanic/Latino ethnicity is treated not as a race but as a separate, binary identification in addition to the aforementioned race identification.

Definition of the term STEM: The Georgetown University Report[42], cited extensively in Section 3, defines STEM occupations to include five major subgroups: Computer occupations; Mathematical Science occupations; Architects, Surveyors, and Technicians; Engineers and Engineering Technicians ; and Life and Physical Science occupations. It excludes social scientists and healthcare professionals. This report uses two terms: STEM workers (any person aged 25-54 working in a STEM occupation as previously defined) and STEM majors (those workers aged 25-54 who have a Bachelor's degree in a STEM field who may work in any occupation).

The **Science & Engineering Indicators 2012** report[43] loosely uses the term STEM in a similar way to the Georgetown report, but primarily focuses more narrowly on Science & Engineering ('S&E') occupations and majors (which include: biological, agricultural, environmental, and life sciences, computer and mathematical sciences, physical sciences, social sciences, and engineering), which 'are generally associated with a Bachelor's degree level of knowledge and education in S&E fields' (p. 3-7), following the widely-used National Science Foundation's terms of reference. They also designate a category 'S&E-related' which includes health fields, science and math teacher education, technology and technical fields, architecture, and actuarial science. This category 'also requires some S&E knowledge or training, but not necessarily as a required credential for being hired or at the Bachelor's degree level' (p. 3-7). Taken together, the S&E and S&E-related categories of this report subsume the Georgetown report but also explicitly include social sciences and health fields. In this report, the term 'STEM occupations' designates S&E occupations as well as 'S&E technicians, computer programmers, and

---

41 Xie, Y. & Killewald, A (2012). *Is American Science in Decline?* Cambridge, MA: Harvard University Press.

42 Carnevale, Smith, & Melton, (2011). 'STEM', Washington, DC: Georgetown Center for Education and the Workforce, http://cew.georgetown.edu/STEM

43 Science and Engineering Indicators 2012, http://www.nsf.gov/statistics/seind12/

S&E managers' (p. 3-7). As noted, this report's definition of science & engineering views the social sciences, including psychology, as a core STEM discipline[44]. This view is shared by bodies such as NSF and US Immigration and Customs Enforcement. Also, sectors not traditionally viewed as STEM, such as construction, retail, transportation, or hospitality, were recognized by the Department of Labor as STEM sectors due to the impact technology and innovation has over them, requiring new skill sets from workers[45].

Section 1

In this section of the report, we discuss attitudes toward STEM and STEM education in the US. We begin by discussing the agendas advanced by politicians at the federal and state levels and some background on how STEM is characterized in the most recent reports meant to guide their thinking. Next we discuss a sample of measures of attitudes toward STEM collected from the public – particularly students and parents. Then we present some information regarding the views of employers and finish with a discussion of how STEM is portrayed in the US through various media. There is enough overlap to prevent a complete separation of this discussion into the sections just outlined so, where relevant, we cross-reference reports and data.

I. Government

At the federal level, support for STEM is one of the issues that generally remains above partisan politicking. For example, in the most recent election for President, the leading candidates from both major political parties made it clear that they want to strengthen many aspects related to STEM and innovation in the US[46]. Where differences do surface, they generally revolve around how improvements should be made and how such initiatives will be funded.

This drive to improve STEM education is seen by many as a means to maintain or improve America's economic status in the world. The following excerpt, drawn from a recent report[47] by the President's Council of Advisors on Science and Technology (PCAST) is characteristic of most of the federal rhetoric on these issues:

> The success of the United States in the 21st century - its wealth and welfare - will depend on the ideas and skills of its population. These have always been the Nation's most important assets. As the world becomes increasingly technological, the value of these national assets will be determined in no small measure by the effectiveness of science, technology, engineering, and mathematics (STEM) education in the United States. STEM education will determine whether the United States will remain a leader among nations and whether we will be able to solve immense challenges in such areas as energy, health, environmental protection, and national security … It will generate the scientists, technologists, engineers, and mathematicians who will create the new ideas, new products, and entirely new industries of the 21st century. It will provide the technical skills and quantitative literacy needed for individuals to earn livable wages and make better decisions for themselves, their families, and their communities. And it will strengthen our

44 APA 2010 Report http://www.apa.org/pubs/info/reports/stem-discipline.aspx
45 US Department of Labor, (2007). 'The STEM Workforce Challenge' www.doleta.gov/youth_services/pdf/STEM_Report_4%2007.pdf
46 Scientific American (9/4/2012): http://www.scientificamerican.com/article.cfm?id=obama-romney-science-debate
47 PCAST (2010) p. vii: http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-stem-ed-final.pdf

> democracy by preparing all citizens to make informed choices in an increasingly technological world.

STEM is seen as vital to our future success – not only in terms of cutting edge science, but also to improve the welfare and decision-making of every citizen.

The recent mediocre performance of American students on national and international assessments (discussed in the Introduction) coupled with what some measures indicate as a declining interest in STEM (discussed in more detail in Section 1-II), is what particularly concerns policymakers. As one might expect, a significant portion of the blame for this is laid on teachers and schools. This view is succinctly expressed in the PCAST 2010 *Prepare and Inspire* report:

> Some of the problem, to be sure, is attributable to schools that are failing systemically; this aspect of the problem must be addressed with systemic solutions. Yet even schools that are generally successful often fall short in STEM fields. Schools often lack teachers who know how to teach science and mathematics effectively - and who know and love their subject well enough to inspire their students. Teachers lack adequate support, including appropriate professional development as well as interesting and intriguing curricula. School systems lack tools for assessing progress and rewarding success. The Nation lacks clear, shared standards for science and math that would help all actors in the system set and achieve goals.[48]

Following from this, the report lays out two main objectives: improve student proficiency in STEM ('prepare') and increase the amount of students persisting in STEM ('inspire'). Both of these notions are touched on throughout the report. In particular, more detail on the preparation of students is found in Sections 2 and 4, while discussion of attitudes and attempts to improve them are found in Sections 1 and 4.

In terms of capturing the attitude of those in government toward STEM, President Obama's *State of the Union Address* in 2011, seems to exemplify the focus of his agenda and the similar feelings and ideas of many policymakers at the federal and state levels[49]. As in the 2010 PCAST report that was released a few months before the President's *Address*, the mention of STEM was couched in the larger discussion of competitiveness. With phrases like '[t]his is our generation's Sputnik moment' and '[t]he future is ours to win' the President recalled a time in our past when the nation rallied around STEM and looked to recapture this spirit in the name of competitiveness and a secure future. More directly, the President stated: '[t]he quality of our math and science education lags behind many other nations'. Following this, it is interesting that the President first argues that family and parents are the primary group responsible for student engagement and success, noting that we need to celebrate science fair winners alongside sports champions. When he turns the focus to schools, the President sets up discussion of his Race to the Top[50] competition for reforming education by claiming that the rigor and expectations for and performance of students in schools is often too low. Despite this criticism, the President – as many politicians will do – then turns to a

---

[48] PCAST (2010) p. viii: http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-stem-ed-final.pdf

[49] Obama, B. (2011). *State of the Union Address*. All quotes taken from full text available here: http://www.whitehouse.gov/the-press-office/2011/01/25/remarks-president-state-union-address

[50] http://www2.ed.gov/programs/racetothetop/index.html

success story to galvanize the idea that a good education can give everyone the chance to succeed. He adds that he wants to improve the level of respect for teachers in the US to that equivalent with other nations. Based on the notion of rewarding the good and expunging the bad teachers, the President expresses the goal of wanting to train 100,000 new STEM teachers by 2021.

Shifting the focus to higher education, President Obama touches on three points that he thinks can help the US to lead the world in the proportion of citizens holding college degrees. First, he argues that the government needs to make permanent a one-time US $10,000 tax credit for those who attend college for four years[51]. Second, without details, the President stated the need to revitalize community colleges in America, in an effort to improve the ability of workers to gain re-training for high technology jobs. Third, as a segue into his discussion of the workforce and other issues, the President argues that current immigration policies need to be fixed such that we do not deport the best and the brightest students that come here from other countries.

What has been done about these ideas and agenda items since that speech? In a follow-up on some of these agenda items raised by the President, a recent *Update*[52] regarding the Cross-Agency Priority (CAP) Goal of improving STEM education was released in late 2012. The CAP centers on the goal of producing 1M more STEM graduates by 2020 than would be produced by current rates – an increase of 34%. The CAP *Update* outlines five strategies believed to be critical for reaching the target[53]:

- Identifying and implementing evidence-based practices to improve STEM teaching, and attract students to STEM courses;
- Providing more opportunities for students to do hands-on, real-world STEM activities through research experiences, especially in their first two years of college;
- Addressing the mathematics preparation gap that students face when they arrive at college using evidence-based practices that generate improved results;
- Pursuing a focus on women and underrepresented minorities;
- Identifying and supporting innovation in higher education.

Each of these strategies is discussed in more detail throughout the brief, which generally calls upon findings provided in other PCAST and NRC reports to provide supporting evidence for the need for change and potential interventions, which are usually based on small-case successes. While the ongoing and planned initiatives will be discussed more in Section 4, the *Update* generally demonstrates that increased funding will be dedicated to achieving the strategies outlined above. One difference between this *Update* and many of the associated policy reports on which it is based is the active language used for the Milestones, where dates and specific actions toward meeting the strategies are outlined.

II. Public attitudes

Capturing the nature of public attitudes toward science, and more broadly toward STEM, is a complicated task. Aside from the methodological challenges and concerns about

---

[51] In the US, a ‘typical’ Bachelor’s degree is completed within 4-5 years.

[52] Full text available here: http://goals.performance.gov/node/38577

[53] Quoted from pages 2-3 from CAP brief (2012).

how much the public understands about science topics and research, there are certain topics in STEM that are strongly associated with political or religious viewpoints. For example, topics related to evolution, global warming and stem-cell research are politically divisive. Additionally, while many think that science and math education need to be improved nationally, many also report that they are satisfied with the education their children receive in local schools.

When looking at the general feelings of the public toward STEM, research on students generally seems to indicate that there is a distinction between a general positive feeling or appreciation for science and variability in enjoyment for the science received in school[54].

In this section we present a sampling of the data that give a snapshot of public attitudes toward STEM in the US. These data come from a variety of datasets and studies. Unless it is particularly noteworthy, we generally leave detailed specifics about sampling and methods out of the presentation, but provide citations where more information can be found.

In a number of the recent administrations of NAEP (see Table 1.1), nationally representative samples of 4th, 8th and 12th grade students were asked items about their attitude toward science and math by having them rate their level of agreement with statements like: '*I like science'* or '*Math is one of my favorite subjects'*. The '*I like science'* and *'I like math'* items have been used in numerous rounds of NAEP. Looking at data for science and mathematics going back to the 1990s, the picture is mixed, but much of this may be due to a change in the item response options in recent years. For math, since 1990 there was a general decline of about 10 points in the percentage of students who agreed (i.e., Agreed or Strongly Agreed) with the statement about liking math up until 2003. The question was not used on the 2005 and 2007 NAEP in math, but when it was used in 2009 and 2011, the responses indicated that approximately 65% of students agreed with liking math. However, in the two most recent surveys there was no *Undecided* option for students and it seems that this is more likely the root of the change in student attitudes than a significant shift in student feelings. For science, the data from 1996 to 2003 showed generally no changes in the percentage of students agreeing with the '*I like science'* prompt during that period. With the most recent surveys in 2009 and 2011, the *Not Sure* option was dropped and the percentage of students responding that they *Agree* or *Strongly Agree* with the prompt jumped approximately 15% points from earlier values. While the results likely provide some bracketing to the percentage of 8th students in the US who like science and math, the recent shift provides a cautionary example about how such results can be influenced by seemingly small changes in item wording.

Despite these reservations about precisely modeling longitudinal changes in student attitudes, these values do allow for comparisons across genders and racial groups. For both math and science, there are generally consistent gaps that exist between male and female students, with higher percentages of male students indicating that they like math and science than their female peers. This difference is slightly larger in science than in math. Comparing students from different racial and ethnic groups reveals that in

---

[54] Osborne, J., Simon, S., & Collins, S. (2003). Attitudes towards science: a review of the literature and its implications. *International journal of science education*, *25*(9), 1049-1079.

mathematics, a greater proportion of students who are Asian/Pacific Islander or Black agree with liking the subject. The percentages of Hispanic and White students indicating that they like math are nearly identical across the years, and mostly 5-10 points below API or Black students. The results for American Indian/Alaska Native (Native American) students are too variable to draw any substantive conclusion. In terms of science, the patterns are much less clear. From 1996-2005 most groups showed little change in attitudes, with the exception of Native American students who demonstrated a 15 point gain during this time. From 2009-2011, most groups showed moderate gains, but the percentage of Native American students indicating that they like science declined.

Table 1.1. Percentages of 8th Grade students who agreed with statement I like (subject).

Year	White	Black	Hispanic	Asian / Pac. Isl.	Am. Indian / Alaska Nat.
*Math^*					
1990	56	64	58	66	‡
1992	55	65	55	62	‡
1996	54	61	55	‡	‡
2000	52	63	54	61	63
2003	48	55	47	57	44
2009	63	70	64	73	63
2011	63	68	65	76	60
*Science**					
1996	50	52	47	49	39
2000	52	51	47	45	57
2005	52	49	44	51	53
2009	67	62	62	74	68
2011	70	65	66	75	67

Notes. ^Response options for items through 2003 were *Strongly Disagree*, *Disagree*, *Undecided*, *Agree*, *Strongly Agree*. From 2009, options did not include *Undecided*. *Response options for items through 2003 were *Disagree, Not Sure, Agree*. From 2009, options were *Strongly Disagree*, *Disagree*, *Agree*, *Strongly Agree*.

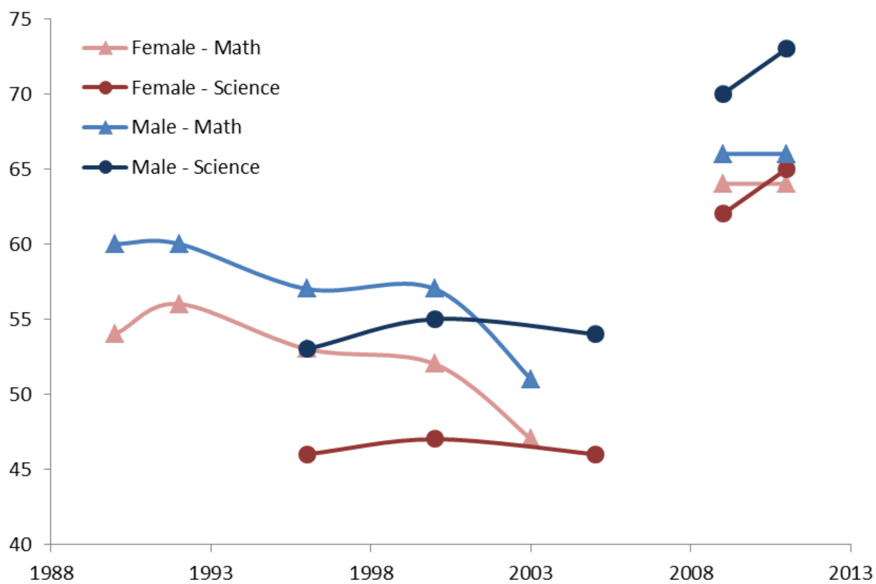


Figure 1.1. NAEP Percentages of 8th Grade students who agreed with statement I like (subject).

In 2011, Microsoft commissioned the surveying of a group of college students studying STEM (n=500) and parents of K-12 students (n=854) about issues related to interest in STEM careers and STEM education[55]. While data from the survey are not available for evaluation, the results are presented in a summary report[56]. The survey asked parents about the job preferences they have for their children, and from the results it seems that half of the respondents indicated that they would like their children to follow a career in STEM - although it is not completely clear how the results were tabulated. Parents gave an overall grade of 'B' on the STEM preparation their children receive from K-12 schools, while 55% of college respondents said that their K-12 experience prepared them *Very Well* or *Extremely Well* for college STEM coursework. In the combined sample, approximately 94% of the respondents indicated that a greater focus on STEM is necessary to provide future generations with key skills. Following from this, roughly 90% of respondents agreed that preparing students for STEM careers should be a top priority of schools, but just less than half agreed that this is a current priority in K-12. When asked why STEM education should be a priority, half of parents responded with reasons related to spurring innovation in the US and maintaining competitiveness in global markets. Significantly lower proportions indicated that a priority on STEM was important to enable students to have good-paying jobs (36%) or fulfilling careers (30%). The majority of college students indicated that they decided to study STEM in high school (57%) or middle school (13%), with another 20% indicating that they did not make this decision until college. When parents were asked about the favorite classes of their children, mathematics edged out art, but each of the science disciplines came in behind reading, history, music and physical education. When students were asked about the factors that were influential in their success as a STEM major, 73% indicated that having a passion for the subject was *Absolutely Essential* or *Extremely Important*, followed by studying hard (67%) and attending a good college (48%). When asked about who was most influential in their decision to pursue STEM, most college students indicated no one in particular (34%), followed by a parent (27%) and then by a teacher (14%). This general trend is matched by a recent survey effort by *Scientific American* magazine[57], where 36% of the sample in STEM (n=2734) reported that they grew interested in science independently, 31% said that a parent was responsible for sparking their interest, and 23% indicated that a teacher was responsible. When asked a similar question about who was responsible for supporting or advancing their interest, the response pattern (n=2429) was a bit different, with 42% claiming that they maintained their interest independently, 24% citing a teacher as the person responsible followed by 22% indicating a parent.

The National Science Foundation's *Science & Engineering Indicators* 2012 report also includes details on public attitudes towards science & technology from a range of studies[58] - see Table 1.2. The results show very strong support for the socioeconomic promise of science & technology and for federal involvement in research, but they echo concerns over the quality of K-12 education. Overall, an overwhelming 91% of adults agree or strongly agree with the claim that science and technology will result in more opportunities for the next generation. There are gender differences in this response,

---

55 http://www.microsoft.com/en-us/news/press/2011/sep11/09-07MSSTEMSurveyPR.aspx
56 Available from: http://www.microsoft.com/presspass/presskits/citizenship/docs/STEM_Perception_Report.pptx
57 Initial data presented here: http://www.scientificamerican.com/article.cfm?id=sa-survey-what-scientists-say
58 Science and Engineering Indicators 2012, http://www.nsf.gov/statistics/seind12/

however, in that only 29% of women 'strongly agree' with this premise while 41% of men do likewise. When considering the results by age and by academic attainment, it seems that larger percentages of young adults strongly agree with the provision of opportunities by STEM than older respondents, and that agreement increases with the level of educational attainment. Overall, the long term trend (1985 onwards) shows that only a small and slightly declining minority (14-16%) of respondents disagree to any extent with the premise that the federal government should fund basic scientific research. There has been a trend towards more prevalent 'strong agreement' with this idea, though this has subsided somewhat since 2006 (when it peaked at 32% of respondents). When asked about the quality of science and math education in American schools, responses since 1985 have changed very little, with consistently 60-70% of respondents indicating some agreement with the idea that science and math education is inadequate.

Table 1.2. Indicators of Public perception of STEM (From NSF Science and Engineering Indicators, 2012)

Appendix table 7-21

Public assessment of whether science and technology result in more opportunities for next generation, by respondent characteristic: 2010.

Characteristic	Strongly agree	Agree	Disagree	Strongly disagree	Don't know
All adults (*n* = 1,434)	35	56	6	1	2
Sex					
Male (*n* = 603)	41	51	6	1	1
Female (*n* = 831)	29	61	6	1	4
Formal education[a]					
<High school (*n* = 186)	26	58	9	3	5
High school graduate (*n* = 443)	33	58	6	1	2
Some college (*n* = 350)	36	58	4	1	1
Baccalaureate (*n* = 300)	36	57	6	*	1
Graduate/professional degree (*n* = 154)	46	44	6	1	3
Age (years)[a]					
18–24 (*n* = 85)	44	53	1	2	0
25–34 (*n* = 279)	33	60	4	1	2
35–44 (*n* = 245)	34	57	6	1	2
45–54 (*n* = 272)	38	56	5	0	1
55–64 (*n* = 261)	34	55	9	*	2
≥65 (*n* = 284)	28	56	8	2	6

* = <0.5% responded

[a]Categories do not add to total *n* because "don't know" and "refused" responses not shown.

[b]Low = ≤5 high school and college science/math courses; middle = 6–8 courses; high = ≥9 courses. Questions asked of 956 survey respondents; categories do not add to total because "don't know" and "refused" responses not shown.

[c]Quartiles based on percentage of nine questions in trend factual knowledge of science scale answered correctly. See notes to appendix table 7-8 for questions.

NOTES: Percent of responses to *Because of science and technology, there will be more opportunities for the next generation.* Percentages may not add to 100% because of rounding.

SOURCE: University of Chicago, National Opinion Research Center, General Social Survey (2010).

Appendix table 7-24

Public opinion on whether federal government should fund basic scientific research: 1985–2010.

Year	1985	1988	1990	1992	1995	1997	1999	2001	2004	2006	2008	2010
n =	2,003	2,041	2,005	1,995	2,006	2,000	1,882	1,574	2,025	1,864	2,021	1,434
Opinion												
Strongly agree	9	16	18	14	17	22	21	19	29	32	24	23
Agree	70	65	63	63	61	57	61	62	53	55	60	59
Disagree	16	14	15	18	17	15	13	14	15	8	11	12
Strongly disagree	*	1	1	2	2	3	2	1	2	1	1	2
Don't know	5	4	4	3	3	3	3	4	1	3	4	4

* = <0.5% responded

NOTES: Percent of responses to *Even if it brings no immediate benefits, scientific research that advances the frontiers of knowledge is necessary and should be supported by the federal government.* Table includes all years for which data collected. Percentages may not add to 100% because of

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Public Attitudes Toward and Understanding of Science and Technology (1985–2001); University of Michigan, Survey of Consumer Attitudes (2004); and University of Chicago, National Opinion Research Center, General Social Survey (2006–10).

Appendix table 7-37

Public assessment of whether the quality of science and mathematics education in American schools is inadequate: 1985–2008.

Year	1985	1988	1990	1992	1995	1997	1999	2001	2008
n =	2,003	2,041	2,005	1,995	2,006	2,000	1,882	1,574	2,021
Opinion									
Strongly agree	14	18	24	24	21	23	21	17	21
Agree	49	50	48	51	48	45	42	51	49
Disagree	27	23	22	19	22	22	26	24	22
Strongly disagree	2	2	2	2	3	4	4	2	2
Don't know	8	7	4	4	6	6	7	7	6

NOTES: Percent of responses to *The quality of science and mathematics education in American schools is inadequate.* Table includes all years for which data collected. Percentages may not add to 100% because of rounding.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Public Attitudes Toward and Understanding of Science and Technology (1985–2001); and University of Chicago, National Opinion Research Center, General Social Survey (2008).

International comparisons

In order to provide a comparative picture of the views Americans have on science, we present data from a small set of countries that provide their views on the promise and concerns about science[59]. Table 1.3 compiles data from a series of different studies done to gauge attitudes toward science in different countries, but with similar variables to allow for comparisons to be made. These data present an interesting view of the US, in comparison with other nations. On the one hand, the US seems most similar to South Korea and China in that a large percentage of their citizens believe in the promise of science for improving our lives and expanding opportunities for the next generation. This sets it apart from Japan, India and the European Union in the level of agreement with those ideas. Conversely, there is evidence that a majority of Americans believe that we depend too much on science and not enough on faith, which puts us ahead of all others, spare South Korea, in this regard. Yet, we also lead the group in our lack of agreement with the notions that it is not important to understand science for everyday life and in the belief that science makes our lives change too fast. In sum, Americans are at or near the top of a number of countries in terms of their belief in the importance of STEM and what it can do today and will do in the future. The belief that we do not depend enough on faith is deep-rooted in the fabric of this country and is likely not to change any time soon. However, this does not mean that Americans reject science, and they're unique in this respect among the sample of countries investigated.

59 Science and Engineering Indicators 2012, online at http://www.nsf.gov/statistics/seind12/

Noteworthy limitations of affective data

In interpreting these results, it is important to consider some of the limitations of the data. While some studies like NAEP include a nationally representative sample of students, using single items to represent students' overall attitudes toward science is generally not considered good practice. For the Microsoft data, it is worth remembering that all of the college students surveyed were already studying STEM, and most likely hold different feelings toward these issues than the general population. Similarly, a major issue with much of these data is that for many of these questions respondents were allowed to indicate multiple response categories for each item, which makes the results much more difficult to decipher.

Table 1.3. Percentage of respondents who Agree with statements about science, by country.

Statement	United States (2004 or 2010)[a]	Japan (2001)	South Korea (2008)	China (2001 or 2007)[b,c]	India (2004)	Malaysia (2008)[d]	European Union (2010)
Promise of science							
Science and technology are making our lives healthier, easier, and more comfortable.	90	73	93	86	77	84	66
With the application of science and new technology, work will become more interesting.	76	54	85	70	61	71	61
Because of science and technology, there will be more opportunities for the next generation.	91	66	84	82	54	NA	75
Reservations about science							
We depend too much on science and not enough on faith.	55	NA	54	16	NA	39	38
It is not important for me to know about science in my daily life.	14	25	30	17	NA	NA	33
Science makes our way of life change too fast.	51	62	73	73	75	66	58

NA = not available, question not asked or different response categories offered; S&T = science and technology

[a]U.S. responses to 2004 survey include "Science and technology are making our lives healthier..."; "With the application of science and new technology..."; "We depend too much on science..."; and "It is not important for me to know about science..." Responses to other items are from 2010 survey.
[b]China's responses to 2007 survey include "Promise of science" questions and "We depend too much on science…" China's responses to 2001 survey include "It is not important for me to know about science…" and "Science makes our way of life change…"
[c]Chinese respondents to 2001 survey were given different categories (Agree, Basically agree, Don't agree, Don't know), with no neutral category.
[d]Malaysian question corresponding to "Science and technology are making our lives healthier, easier, and more comfortable" stated as "Science and technology improves the quality of our lives." Question corresponding to "With the application of science and new technology, work will become more interesting" stated as "Our daily work will be more efficient with the use of science and technology." Question corresponding to "It is not important for me to know about science in my daily life" stated in a positive form as "We need to have knowledge about science in order to manage our daily lives"; Malaysian responses of agree and disagree reversed to make them correspond to negative form of statement asked by other countries.

SOURCES: United States—University of Michigan, Survey of Consumer Attitudes (2004) and University of Chicago, National Opinion Research Center, General Social Survey (2010); Japan—Ministry of Education, Culture, Sports, Science and Technology, National Institute of Science and Technology Policy, *The 2001 Survey of Public Attitudes Toward and Understanding of Science and Technology in Japan* (2002); Korea—Korea Foundation for the Advancement of Science and Creativity (formerly Korea Science Foundation), *Report: Survey of Public Attitudes Toward, and Understanding of Science and Technology* (2006), Korea Gallup; *National Understanding of Science and Technology: Survey Report Results* (2009); Russia—Gokhberg L and Shuvalova O, *Russian Public Opinion of the Knowledge Economy: Science, Innovation, Information Technology and Education as Drivers of Economic Growth and Quality of Life*, British Council, Russia (2004); China—Chinese Ministry of Science and Technology, *China Science and Technology Indicators 2002* (2002); India—Shukla R, *India Science Report: Science Education, Human Resources and Public Attitude towards Science and Technology*, National Council of Applied Economic Research (2005); Malaysia—Malaysian Science and Technology Information Centre, *Public Awareness of Science and Technology: Malaysia 2008* (2010); and EU—European Commission, Special Eurobarometer 340/Wave 73.1: *Science and Technology Report* (2010).

Science and Engineering Indicators 2012

I. Employers

While employment trends will be discussed more in Section 3 of the report, we feel confident in claiming that corporations and small companies that are in any way related to STEM are paying attention to trends in STEM degree production with interest as this directly effects their ability to do business. As we will discuss more later, there is a common argument over whether or not there are 'enough' STEM-educated or - trained citizens to meet the needs of our knowledge-based economy today or into the future. Employers do not seem to see this issue as a simple matter of supply and demand, but the need to have ample supply so that they can hire the most talented.

To illustrate this, we present a related anecdote based on a discussion we had with an individual who was the director of hiring for one of the largest employers of STEM PhD researchers in the US. During the discussion, this director brought up the notion that not all PhDs are created equally, meaning that there is definitely a range of skills from those who are fully capable of carrying out independent investigations down to those who are merely advanced technicians. He went on to say that of all the PhDs produced each year, he was only interested in hiring the top 25%, because those are the scientists that will drive research and development for the company. He had clearly 'done the math' with projected values for supply and demand and his major concern was that with the pending retirement of 'baby boomers' in the US over the next 20 years, there would not be enough qualified young researchers to fill their vacancies nor the ones created by growing markets. This concern is echoed by projections from the Bureau of Labor Statistics[60], which documents employee shortages over the next decade in STEM fields. Thus, the director did not see this as an issue of an overall shortage of those with the correct degrees in hand, but more about improving the percentage of degree holders that were capable of independent research.

So what does the threat of a shortage of well-trained workers lead these companies to do? We next briefly outline a few cases to document the spectrum of responses. First, as discussed in the prior section on public attitudes, Microsoft recently commissioned a survey of STEM majors and parents regarding the preparation and expectations of students for pursuing STEM in school and careers. While the data are informative, at this point it is not clear if or how Microsoft might act on the data they collected.

Another case is illustrated by the documentary film *Two Million Minutes*[61]. The film was produced by Robert Compton, a former IBM engineer who became a successful venture capitalist associated with many STEM-related companies. In a public forum at Indiana University, Mr. Compton cited that one of the main reasons he made the movie was because his companies struggled to find enough good talent in the US and had to consistently turn to hiring people from China and India to fill their open positions. The movie was meant to explore differences in the preparation and work-ethic between top-level students from America, China and India. The cases presented, while clearly not a representative sample of students, send the message that American students may be talented, but are underachieving and less motivated to excel than their peers in Asia.

---

60 Lacey, T. A., & Wright, B. (2009). Occupational employment projections to 2018. *Monthly Labor Review, 132*(11), 82–123.

61 More information can be found here: http://www.2mminutes.com/

Probably the largest outward demonstration of employers' attitudes toward STEM and STEM education is manifested in the non-profit organization *Change the Equation*[62] (CTEq), which was created in 2010 as part of President Obama's *Educate to Innovate* initiative. Similar to the federal goal to coordinate STEM efforts across agencies discussed in Section 4, CTEq was created to synchronize efforts by its partners and to maximize the effects of their programs. Members of CTEq include many American companies with a global footprint[63] that have a vested interest in STEM, including: Boeing, Chevron, Dell, DuPont, Intel, Raytheon, Viacom and Xerox. As the outward face of the organization, CTEq's website organizes statistics about STEM attitudes, performance, educational attainment and employment. While the organization visibly seems to be informing and organizing the efforts of its members, it is not clear how it will affect STEM and STEM education as it matures.

In related efforts, ExxonMobil has played a visible role in improving STEM education by putting together a series of commercials that include representations of the mediocre performance of American students on international assessments and offering an inspirational message about how we can 'solve' this issue[64]. ExxonMobil also commonly plays commercials during televised PGA golf events that inform viewers of the [Phil] Mickelson ExxonMobil Teachers Academy, which is one of a number of efforts the company created to improve STEM education by working with students and teachers.

Thus, while a number of companies have substantial efforts to improve STEM performance, and many are concerned with how we might get more students to pursue careers in these fields, no single model of activism has manifested dramatic change. The organization of efforts through CTEq makes logical sense for coordination, but the effects of these efforts is an area that definitely requires more research and evaluation.

II. Community and media

There are a number of ways that Americans are exposed to STEM through the media, and there exists an ever-expanding range of platforms for consuming media including via print, radio, video, digital and increasingly mobile. The myriad platforms coupled with the growing ability to tailor exposure to content closely aligned with one's specific interests, makes it quite possible to avoid any significant exposure to STEM content if that is not part of an individual's personal or family interests.

On balance, there is definitely no dearth of STEM-related content available for consumption. On broadcast television there are popular STEM-related comedies (e.g., *Big Bang Theory*) and dramas (e.g., *CSI*, *Numb3rs*), as well as educational programming for all ages on channels of the Public Broadcasting Service (PBS) (e.g., *Sid the Science Kid*, *Nova*, *Nature*). On cable television there is a much wider array of programming with a handful of channels that run related programming at all times, including the Discovery Channel[65], Science Channel, The Learning Channel, and the National Geographic Channel. On these channels there is a recent trend toward showing reality TV shows instead of more traditional STEM-content programs, yet it is not clear if this is having any effect on viewers' attitudes or understanding of STEM.

---

62 More information can be found here: http://changetheequation.org/

63 Member information here: http://changetheequation.org/members

64 Examples visible here: http://www.exxonmobil.com/Corporate/community_math.aspx

65 Discovery Communications (http://dsc.discovery.com/) controls many stations showing STEM-related content.

One of the most noteworthy programs in recent times is *Mythbusters*[66]. While the show includes many explosions and much destruction, the level of 'rigor' of the investigations shown and attention to alternative hypotheses has increased noticeably over the past few years. The hosts have attained iconic status as *de facto* replacements of earlier science 'celebrities' including Mr. Wizard and Bill Nye the Science Guy. Anecdotally, many educators credit this show with engaging viewers in thinking about STEM and with educating them about the 'scientific method'.

Despite all of these forms of media available, we are not aware of any comprehensive research that documents the effect of this exposure on changing attitudes toward STEM. Over the past few years there have been a few print and TV advertisements broadly related to improving STEM in the US (as noted previously), but these are not very common and, except for those produced by ExxonMobil, they are clearly associated with improving a corporation's image rather than getting more people interested in STEM. The NSF commonly sponsors programming on PBS, but otherwise there is little visible connection between media and STEM-related organizations. In sum, if you want to find a program or podcast that involves STEM, it is quite easy to do so, but it is not clear that this availability is changing citizens' attitudes in any way.

Section 2

In this section we present information related to the academic preparation of students across elementary, secondary and tertiary schooling. We begin with a brief overview of STEM content offered in K-12, and include relevant information about the educators delivering that content. Next we discuss student attainment in STEM, focusing on enrolments in secondary and tertiary institutions as well as degree attainment in undergraduate and graduate programs. We finish with a brief discussion of gender issues related to post-secondary enrolment.

I. Overview of K-12 STEM offerings

Given that there is no single curriculum that is mandated for use nationwide, there is substantial variability in what STEM material students are exposed to in elementary and secondary school. The 2012 National Survey of Science & Mathematics Education provides a prescient report on teacher preparation and STEM offerings in the American K-12 system. A frequent point of concern and attention in K-12 science and mathematics offerings is the perceived lack of appropriate content preparation of teachers.[67]

At the elementary level, only 4% of teachers hold a science degree (any science discipline) which rises to 5% if science/science education dual majors are included. Similarly, 4% of elementary teachers hold a degree in mathematics or math/math education. When queried, most (77%) of these teachers feel very well prepared to teach mathematics but only 39% feel similarly with respect to science teaching. This is reflected in the frequency and extent of class time spent on these subjects: most elementary teachers teach math every day (with an average instructional time of nearly

[66] More information available here: http://dsc.discovery.com/tv-shows/mythbusters

[67] Unless otherwise cited, data referenced in this section are taken from the National Survey of Science and Mathematics Education (2012): http://www.horizon-research.com/2012nssme/

60 minutes), whereas only 20% of Grade K-3 and 35% of Grade 4-6 teachers reported covering science every day, with an average of 19 minutes of instructional time. Some of this difference is likely attributable to the focus on math assessments as part of NCLB, as we discuss in the Introduction.

At the middle school level, teacher preparation is somewhat better, though still lacking in the opinions of many. Twenty-six percent of teachers at this level hold a science degree (41% if science education majors are included) and 23% hold a mathematics degree (35% including math education majors). This is partly a reflection of the separation of disciplinary subjects into distinct classes that usually occurs around 5th or 6th grade. Starting in middle school and continuing through high school, mathematics and science courses are typically organized as a sequence of courses in specific topics. Normally, science offerings include earth/space science, life science, and physical science courses (the sequencing of these subjects depends on the school district and personnel). The mathematics sequence is somewhat more standardized, with algebra or pre-algebra courses commonly available by the 8th grade. However, the mathematics sequence is often not begun by students until high school. Seventy-five percent of middle schools offer a first class in algebra and 25% offer a first class in geometry, yet most students take neither in middle school.

In high school, math and science classes continue to be separated into topical courses. There is no prescribed course progression, but there is a common practice for college-bound students to complete courses in biology, chemistry, and physics, often in that order (see Figure 2.1). Courses in earth sciences and physical sciences are frequently offered but these may be completed by students who are not college-bound or at least not bound for STEM majors. The previously-mentioned mathematics sequence, sometimes begun in middle school, includes Algebra I, Geometry, Trigonometry (or Algebra II), Pre-Calculus, and Calculus. Courses in statistics and other advanced topics (including advanced calculus) are sometimes offered. Teacher preparation again appears better than middle school, with 61% of high school science teachers holding a science degree (82% including science education majors) and 52% of math teachers holding a math degree (73% including math education majors). One major caveat is that this level of preparation is not consistent across science fields: notably, high school physics teachers hold physics degrees only 20% of the time (29% of high school physics teachers have no advanced physics coursework at all).[68]

[68] National Survey of Science and Mathematics Education (2012) 'The Status of High School Physics Teaching', http://www.horizon-research.com/2012nssme/wp-content/uploads/2013/01/AAPT-presentation-final3.pdf.

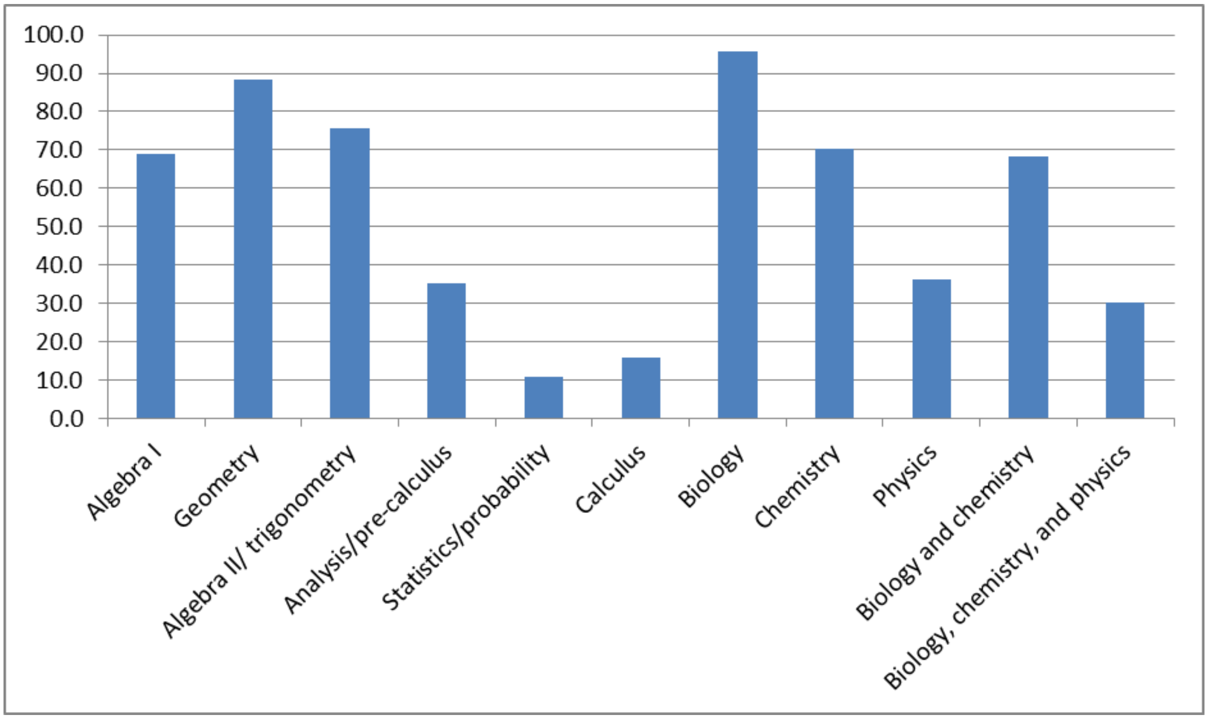


Figure 2.1. Percentage of high school graduates who completed selected mathematics and science courses, 2009. [Source: NCES 2009]

The National Survey of Science and Mathematics Education (2012) also offers an interesting snapshot of how class time in mathematics and science is spent (see Figure 2.2). While traditional, direct lecturing is reported to occur at least weekly by nearly all science and math teachers (at the elementary, middle, and high school level), discussion, ‘hands-on’ activities, and other more student-active practices are reported by teachers to occur at least weekly in a large majority of these classrooms.

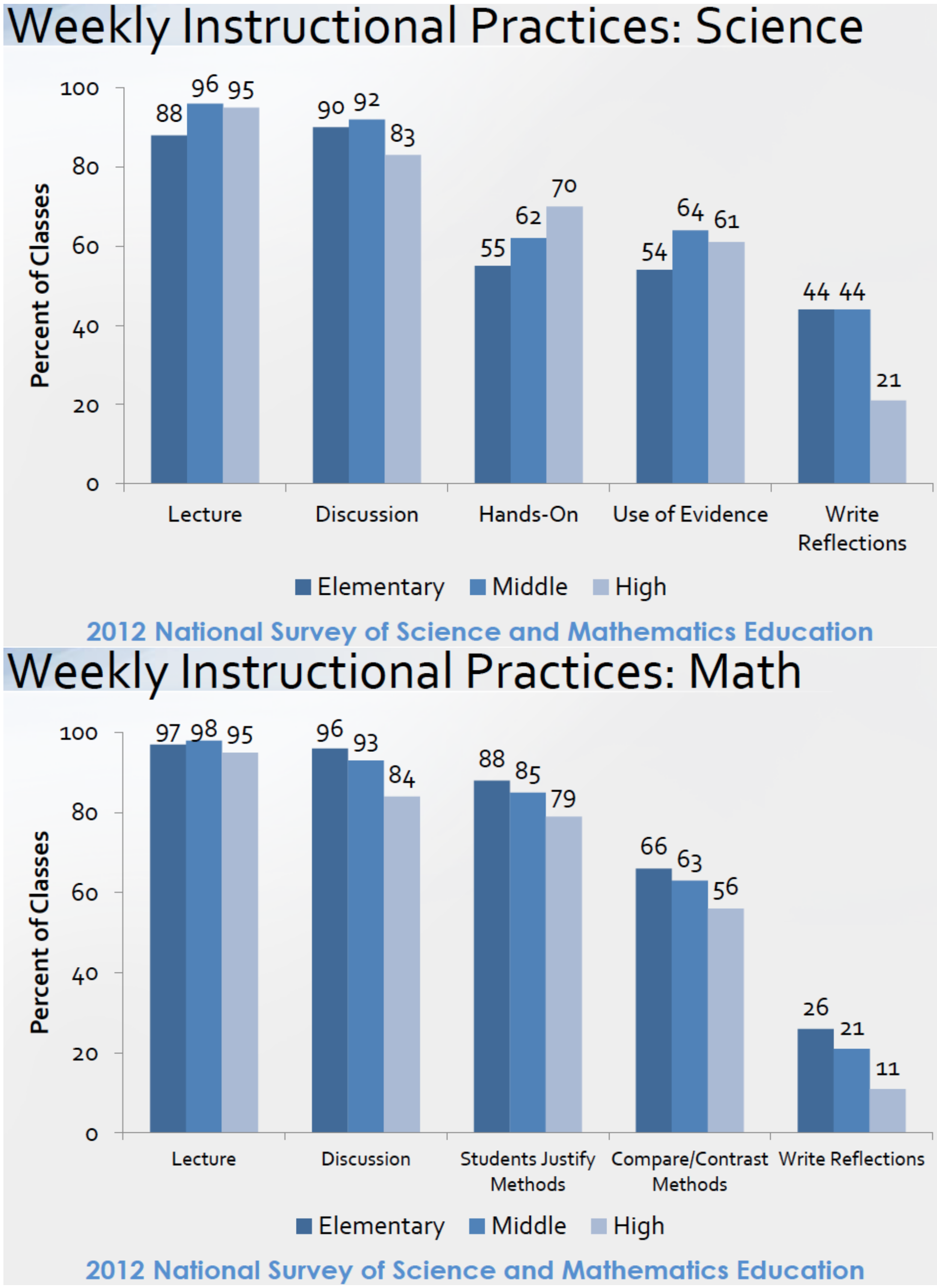


Figure 2.2. Weekly instructional practices in science (top) and math (bottom), as reported by teachers in the National Survey of Science and Mathematics Education[69].

The Advanced Placement[70] (AP) program is widespread in US high schools, which is coordinated by the for-profit College Board. Over 50% of high schools offer AP mathematics with Calculus as the main offering; and 47% of high schools offer at least one AP science class, with most offering biology and then chemistry. AP courses are

69 Figures copied from NSSME presentation to NSF (January 9, 2013), available here: http://www.horizon-research.com/2012nssme/wp-content/uploads/2013/01/NSSME-bag-lunch-at-NSF.pdf

70 More information can be found here: http://apcentral.collegeboard.com

represented as being 'equivalent' to introductory college courses, and high scores (typically a '4' or '5' out of a possible score of '5') on the associated, nationally-standardized AP exams are commonly accepted for college credit in both 2- and 4-year institutions.

There are a plethora of special programs offered at various scales across the country that focus on infusion on STEM into the K-12 curriculum and in afterschool settings. Of particular note are STEM-related magnet programs found in most areas (e.g., New Tech[71] schools, health magnets[72]), specialized curricula (e.g., Project Lead the Way[73]), and informal programs that offer students a chance to be involved with STEM outside of school (e.g., First Robotics[74], MAKER[75], 4-H[76]). The programs listed here only represent a small fraction of those available, but we felt a more comprehensive discussion of programs is beyond the scope of this report.

II. Enrolments in STEM disciplines at all levels

In order to understand more clearly the student-level outcomes arising from the offerings outlined in Section 2.I, this section outlines enrolments in high school STEM courses and post-secondary STEM courses.

Secondary school

At the secondary level, lower mathematics courses (Algebra I, Algebra II/trigonometry, and geometry), are completed by a large majority of high school graduates (upwards of 75%), as is at least one biology course (over 90%) and a chemistry course (two-thirds of graduates). As discussed previously, Algebra I is sometimes completed in middle school so this bar appears artificially lower. (See Figure 2.1 for an illustration.) On the other hand, advanced mathematics – including pre-calculus, calculus, and statistics – are notably less frequently studied. This is significant because of the importance of these subjects, particularly, calculus, to successful post-secondary studies in STEM. Calculus often plays a 'gate-keeping' role in post-secondary programs.

Similarly, physics is studied by less than 40% of high school graduates (a fraction which has increased since the 1980's). Primarily due to the lack of physics coursetaking, Figure 2.1 also illustrates that only about 30% of high school students have taken a course in *each* of biology, chemistry and physics before graduation. With respect to gender, there are small-to-negligible differences between males and females in terms of high school science and mathematics enrolment, with small differences in some specific courses generally falling in favor of females.[77]

Post-secondary school

71 http://www.newtechnetwork.org/
72 http://silva.episd.org/welcome/index
73 http://www.pltw.org/
74 http://www.usfirst.org/
75 http://blog.makezine.com/2013/01/04/young-makers-opens-its-biggest-season-ever/
76 http://www.4-h.org/
77 Laird, J., Alt, M., & Wu, J. (2009). 'STEM Coursetaking Among High School Graduates, 1990-2005', MPR Research Brief.

A recent trend in U.S. post-secondary enrolments, driven in part by the rising cost of education, is enrolments in 2-year institutions, which primarily award Associate's degrees and non-degree certificates. In fact, a large number of certificates related to STEM are awarded by 2-year institutions especially in computer, mathematics, and engineering technician occupations.[78] In many cases, students with intentions towards Bachelor's degrees spend two years at a smaller, local, and/or more inexpensive institution before transferring to a traditional 4-year institution to complete a Bachelor's degree program. A well-known, typical example is provided by Miami-Dade College (MDC), a multi-campus, 2-year institution in Florida which serves over 160,000 students every year. Of those MDC students who complete Associate's degrees, 84% immediately transfer to a 4-year institution elsewhere in the state of Florida to continue their studies.[79] As mentioned when discussing President Obama's 2011 *State of the Union Address*, there is renewed attention to community/technical colleges as institutions that can help students keep their educational costs down and can provide older students with retraining for new, more technical careers.

Overall, Figure 2.3 illustrates the relative proportion of various degree ranks by STEM discipline[80]. Notably, STEM disciplines continue to award far greater numbers of Bachelor's degrees than other ranks of degree. One exception is the 'engineering technology' subfield, which largely involves 2-year degree offerings. Note also that health-related professions, much larger than the other groupings, award more Associate's degrees than other ranks. This is most likely due to the number of professional health and related opportunities – including registered nurses, medical assistants, EMT paramedics, and others.[81]

Vocational education and training (VET), also described as 'career and technical education (CTE)' in the US, is prevalent at the secondary, post-secondary and adult education (e.g. continuing education and/or re-training) levels. The report *Career and Technical Education in the United States: 1990 to 2005*[82], the fourth and most recent in a series of reports on CTE, describes the scope of CTE thusly:

> In high schools, CTE encompasses family and consumer sciences education, general labor market preparation, and occupational education, and may form part of a course of study leading to college, employment, or both. At the postsecondary level, career education is linked to preparation for employment in specific occupations or careers, although postsecondary credentials in career fields may also lead to further education. Adults may participate in formal education and training to acquire, maintain, and upgrade their workforce skills.[83]

[78] Carnevale, Smith, & Melton, (2011). 'STEM', Washington, DC: Georgetown Center for Education and the Workforce, http://cew.georgetown.edu/STEM, Appendix B.

[79] See http://www.mdc.edu/main/about/facts_in_brief.aspx for recent statistics.

[80] T.D. Snyder, & S. Dillow. Digest of Education Statistics 2012 Advanced . National Center for Education Statistics. Table 292.

[81] Ibid, Table 285.

[82] Levesque, K., Laird, J., Hensley, E., Choy, S. P., Cataldi, E. F., and Hudson, L. (2008). 'Career and Technical Education in the United States: 1990 to 2005' National Center for Education Statistics Report 2008-035: Institute of Education Sciences, U.S. Department of Education: Washington, DC.

[83] Levesque, K., Laird, J., Hensley, E., Choy, S. P., Cataldi, E. F., and Hudson, L. (2008). 'Career and Technical Education in the United States: 1990 to 2005' National Center for Education Statistics Report 2008-035: Institute of Education Sciences, U.S. Department of Education: Washington, DC. p. iii.

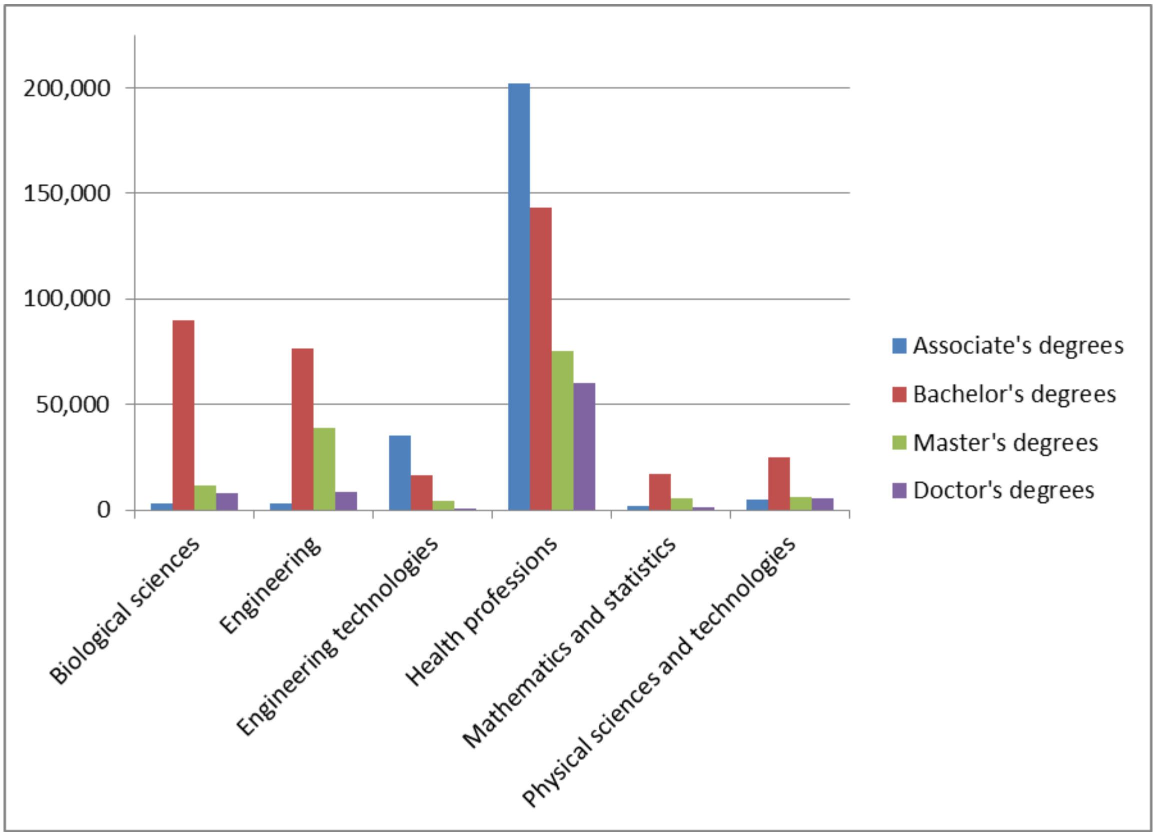


Figure 2.3. Number of degrees awarded in various STEM disciplines, by rank of degree, 2010-2011 academic year.

Thus, despite having a somewhat different construction and goals than *traditional* STEM education, some CTE activities can be fairly described as part of the STEM education system in the US, including disciplines described as ‘academic’ (programs related to many traditional STEM disciplines including physical and biological sciences) and ‘career’ (including STEM-related disciplines such as agricultural & natural resources, applied health – nursing, optometry, etc, and computer/information sciences) in this report.

Between 1990 and 2005, little change was noted in the levels of secondary school participation in CTE, with over 90% of high school students taking at least one such class – health sciences and computer sciences being two of the top three most commonly-studied ‘occupational programs’. At the post-secondary level, a large number of the Associate’s degrees indicated in Figure 2.3 as well as non-degree certificates are connected to CTE programs; the fraction of students in the 2003-4 academic year enroled in certificate programs who were pursuing ‘career fields’ was 81.1%, while the fraction of Associate’s degrees students pursuing a ‘career field’ was 64.4%. At both the secondary and post-secondary level, participants in CTE came from ‘less advantaged educational backgrounds’, reflecting the relevance and accessibility of these programs to such students.[84]

[84] Levesque, K., Laird, J., Hensley, E., Choy, S. P., Cataldi, E. F., and Hudson, L. (2008). ‘Career and Technical Education in the United States: 1990 to 2005’ National Center for Education Statistics Report 2008-035: Institute of Education Sciences, U.S. Department of Education: Washington, DC.

At the beginning tertiary level, STEM coursetaking represents approximately one quarter of all first year course credits earned among students who are beginning either Bachelor's (4-year) or Associate's (2-year) degrees (See Tables 2.1 and 2.2). A large majority (86.9%) of Bachelor's degree students and 78.3% of Associate's degree students attempt at least one STEM credit in their first year of college. However, in parallel with coursetaking at the secondary level - in terms of mathematics courses taken in the first year of college - barely 21.2% of Bachelor's degree students and only 3.4% of Associate's degree students take Calculus or other advanced college mathematics course in their first year of college. Over one third of Bachelor's students and virtually one half of Associate's degree students take no math whatsoever in their first year of enrolment, likely indicating that they have discontinued any further meaningful STEM studies.

Table 2.1. STEM coursetaking in the first year by 2003-4 beginning Bachelor's and Associate's degree students, through 2009.[85]

Student Cohort	Percent attempting any STEM credits	Percent earning any STEM credits	Average number of STEM credits earned	Percent of all earned credits that were STEM
Bachelor's degree	86.9	81.5	9.1	27.2
Associate's degree	78.3	67.1	7.8	26.8

Enrolment in STEM majors has been fairly steady in proportion to the overall college population in the past few years, though as mentioned earlier, these enrolments are considered to be too low for US socio-economic goals.[86] Figure 2.4 compares the percentages of enroled students in various fields during the academic years 2003-4 and 2007-8[87], respectively. In terms of STEM disciplines, few substantial changes are seen in the intervening four years. Life & physical sciences as well as health fields saw a small, marginal uptake in the fraction of students enroled in those disciplines, while engineering, computer science & mathematics are virtually unchanged.

[85] STEM in Postsecondary Education: Entrance, Attrition, and Coursetaking Among 2003–04 Beginning Postsecondary Students, NCES 2013-152, October 2012, Table 5, p. 18.

[86] See, for example, Engage to Excel: Producing One Million Additional College Graduates with Degrees in STEM. (2012). http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-stem-ed-final.pdf.

[87] Note that the Digest of Education Statistics does not report total enrolment by discipline every year; the most recent comparison years are 2003-4 and 2007-8, taken from the 2012 edition of the Digest.

Table 2.2. Highest math course in the first year amongst 2003-4 beginning Bachelor's and Associate's degree students, through 2009[88]

Student Cohort	No math (%)	Precollege-level only (%)	Introductory college-level (%)	Calculus and advanced math (%)
Bachelor's degree	40.1	8.7	30.1	21.2
Associate's degree	49.1	24.5	22.9	3.4

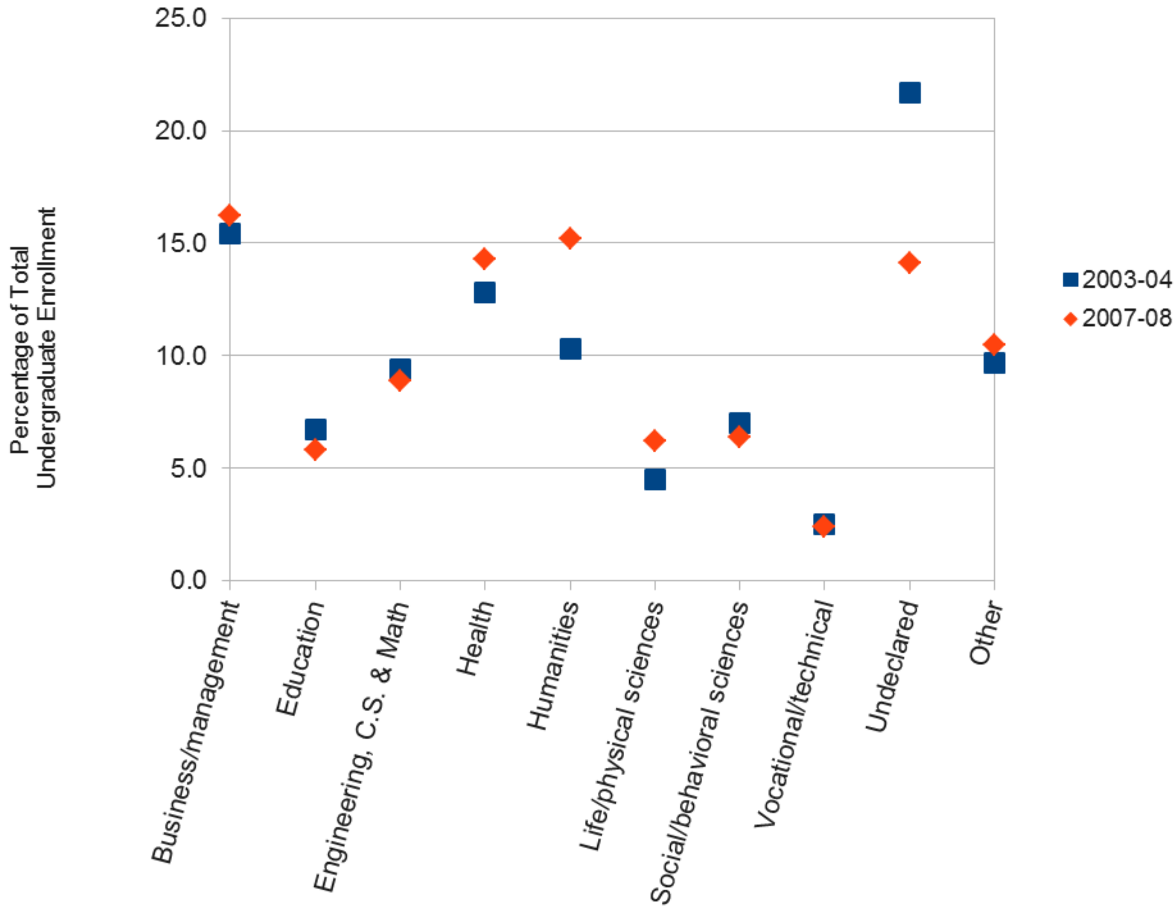


Figure 2.4. Percentage of all undergraduate students enroled in post-secondary institutions in various disciplines, academic years 2003-4 and 2007-8. [Source: Digest 2012, Table 242.]

The number of Bachelor's degrees awarded in STEM has generally increased over the past four decades (Figure 2.5). Health professions and the biological sciences have experienced substantial growth since 1970 (faster than the average growth in college degrees as a whole) and award more degrees than other STEM fields. On the other hand, the physical sciences and mathematical sciences have seen more modest (nearly flat) growth in the same period, which is slower, in fact, than the average growth in college degrees in this period. Engineering has barely 'kept up' in this sense.

88 STEM in Postsecondary Education: Entrance, Attrition, and Coursetaking Among 2003–04 Beginning Postsecondary Students, NCES 2013-152, October 2012, Table 7, p. 23.

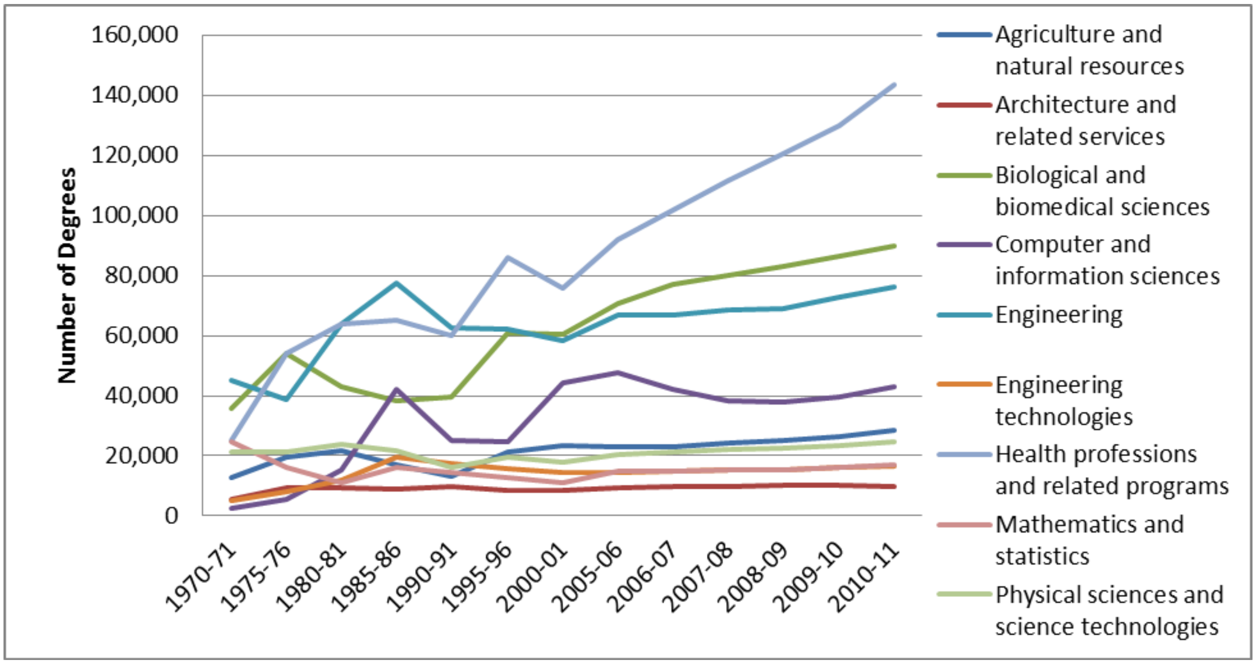


Figure 2.5. Growth Trends in Post-Secondary STEM Degrees, 1970-2010 academic years. Note change in time scale after 2005. [Source: Digest 2012]

A broader snapshot of the relative size and popularity of STEM disciplines appears in Figure 2.6[89]. The total number of degrees awarded in various STEM fields at all levels (Associate's, Bachelor's, Master's, doctoral degrees as well as certificates of less than 2 years duration) is often substantially smaller than non-STEM fields. Engineering, physical & geosciences, and mathematical & computer sciences remain much smaller than, for example, business & management. One apparently large category is science & engineering technologies, which in fact includes a large number of non-degree certificates of less than 2 years duration (287,401 out of a total of 465,900 in this category).

[89] National Center for Education Statistics, IPEDS Data 2010, retrieved from WebCASPAR Database.

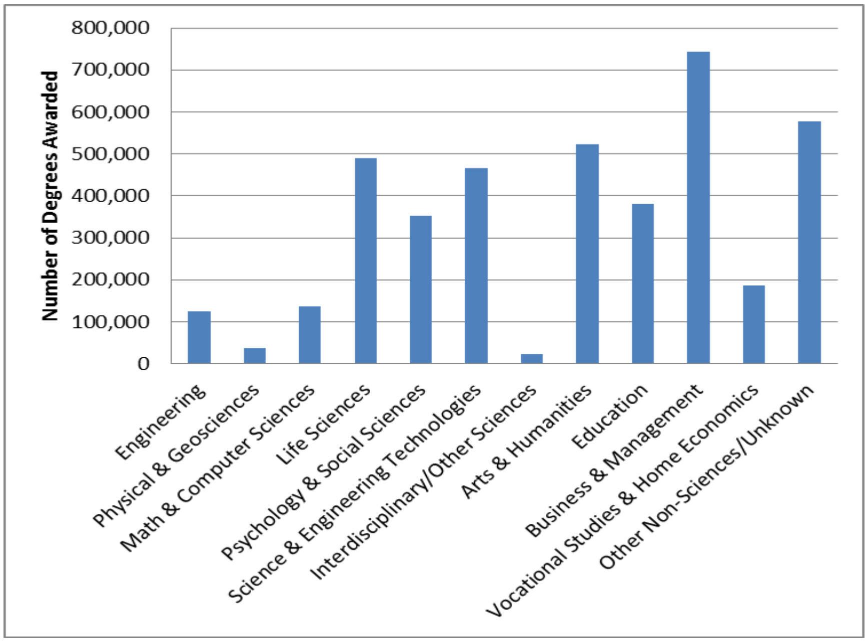


Figure 2.6. Degree Attainment by Broad Category, 2010. Represented is the total number of degrees in each category including Associate's, Bachelor's, Master's, and doctoral degrees as well as certificates of less than 2 years duration.

Similarly, growth projections for the next decade indicate that the number of Bachelor's degrees (and higher) in STEM fields should grow, in absolute terms, but will continue to lose ground to other fields (Figure 2.7).

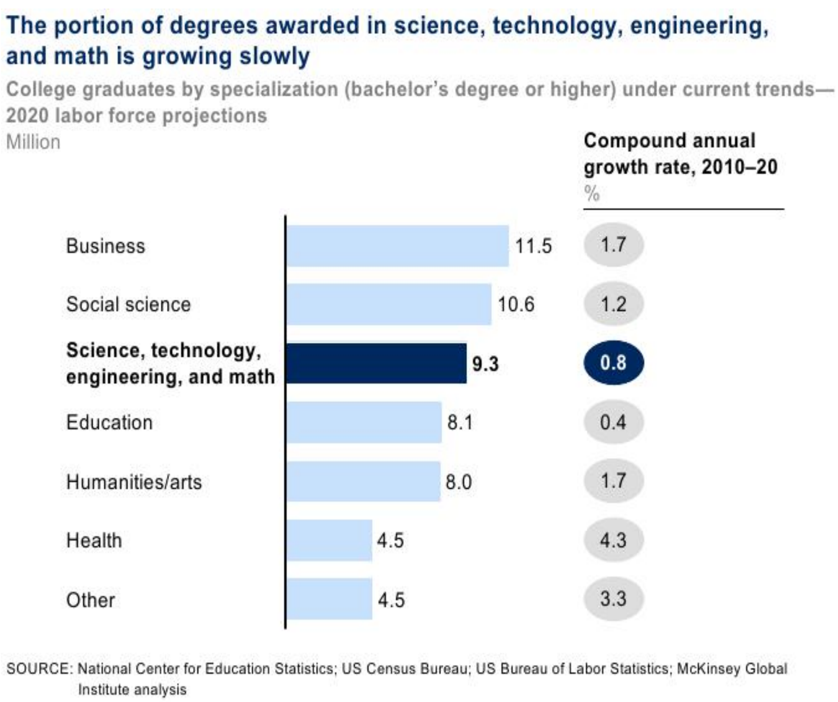


Figure 2.7. Projected growth in number of (Bachelor's and higher) degrees 2010 to 2020. Source: Manyika et al. (2011). An Economy that Works: Job Creation and America's Future. The McKinsey Global Institute.

Beyond the Bachelor's level, the NSF recently reported significant increases in the numbers of students pursuing graduate degrees in STEM[90]. Between 2000 and 2010, total graduate enrolment in STEM programs increased by 35%, while first-time, full time enrolments increased by 50%. Further,

> Although foreign students make up 30% of the total enrolment in U.S. graduate science and engineering programs, and while they constitute a majority in several fields, their slice of the overall pie has not grown in the past decade. Rather, the pools of U.S. citizens and those with temporary visas each grew by 35%.[51]

These positive results should be tempered by the recognition that several fields still have a majority of foreign students, notably some engineering fields and physics, and these increases in graduate enrolments have come during a decade of substantial economic slowdown in the US, which is believed to drive under- and un-employed individuals back to further their education, in order to increase their economic opportunities. This also comes at the end of a decade since 9/11/2001, when there were substantially more limits imposed on foreign visas in the US, which have only partially been relaxed since that time.

Gender issues in post-secondary STEM enrolments

Whereas gender differences exist in enrolments in STEM in the K-12 system, at the post-secondary level these differences often remain larger and more complex. Overall, women now receive a majority of Bachelor's degrees (across all fields) awarded each year in the US. However, in STEM disciplines, representation varies substantially. Women complete nearly three quarters of all life science degrees, but have remained slightly below one in five of all engineering degrees – see Figure 2.8. Even within the indicated groupings, there is substantial variation between sub-fields – physics, for example, awards approximately 22% of Bachelor's degrees to women but chemistry, a larger discipline that weighs the average heavily in the 'physical & geosciences' category, is close to a 50-50 split. Figures 2.9 – 2.11 provide three different snapshots of trends in gender differences in STEM Bachelor's degrees. In particular, Figure 2.11 shows generally positive trends towards more equal representation of males and females in several fields since 1966, with the exception of math/computer sciences and engineering.

Figures 2.9 and 2.10, in particular demonstrate the vast differences in gender equity across the US and over time[91]. Figure 2.9 demonstrates the significant changes in gender balance for those earning degrees in Biology over the last 45 years. The map from 1970 is dominated by small and medium sized blue circles (male dominance) that transform in both size and color through 1990 and on to 2010, where the map is dominated by medium and large gray (gender parity) and red circles (female dominance) that show growth in the overall number of students earning Biology degrees, who are predominantly female. Figure 2.10, which depicts the most recent degree data, shows substantial differences in gender parity across fields. Engineering is still dominated by male students in programs across the US. Degrees in chemistry are roughly equal

[90] J. Mervis, 'U.S. Students Flock to Graduate Science Programs', June 1 2012, http://news.sciencemag.org/scienceinsider/2012/06/us-students-flock-to-graduate.html

[91] For those interested in investigating these figures in more detail, you can access the maps here: http://mypage.iu.edu/~amaltese/maps/

between men and women, but generally these programs are small compared to Engineering and Biology. As mentioned, Biology programs are mixed, but most programs are now at parity or are dominated by female degree earners.

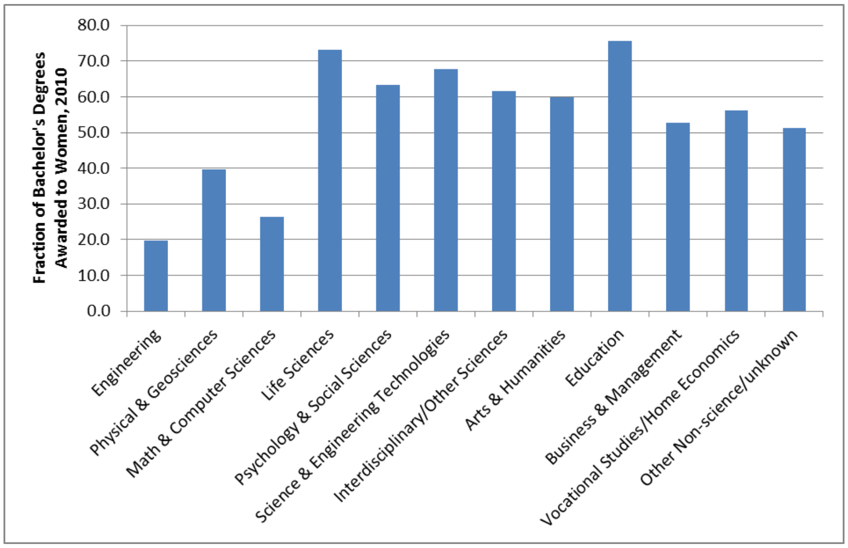


Figure 2.8. Percentage of Bachelor's Degrees Awarded to Females in Various STEM Disciplines, with non-STEM Disciplines as Comparison, 2010. [Source: NCES at Webcaspar]

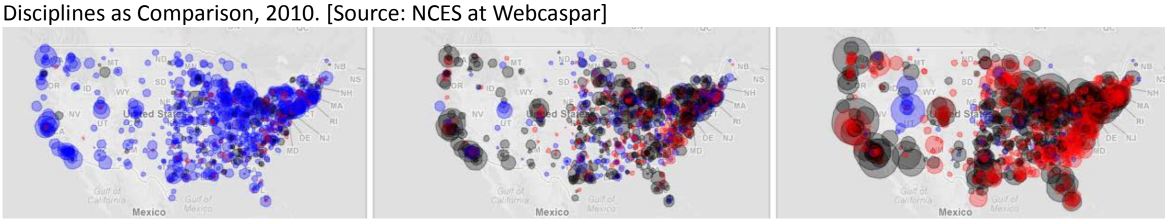


Figure 2.9. Geographic distribution of Bachelor's degrees in Biology at 20-year intervals (1970 (left), 1990 (middle), 2010 (right)). Each institution granting degrees is represented by a circle. The radius of the circle is scaled by the number of degrees awarded. The color of the circle is based on the proportion of degrees awarded to men (blue) or women (red), with grey representing an even split.

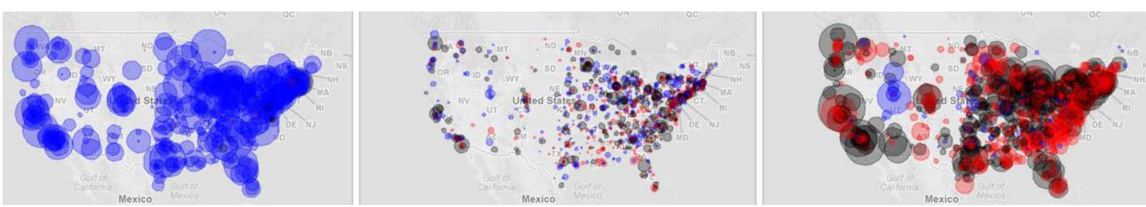


Figure 2.10. Geographic distribution of Bachelor's degrees in Engineering (left), Chemistry (center) and Biology (right) for 2010. Each institution granting degrees is represented by a circle. The radius of the circle is scaled by the number of degrees awarded. The color of the circle is based on the proportion of degrees awarded to men (blue) or women (red), with grey representing an even split.

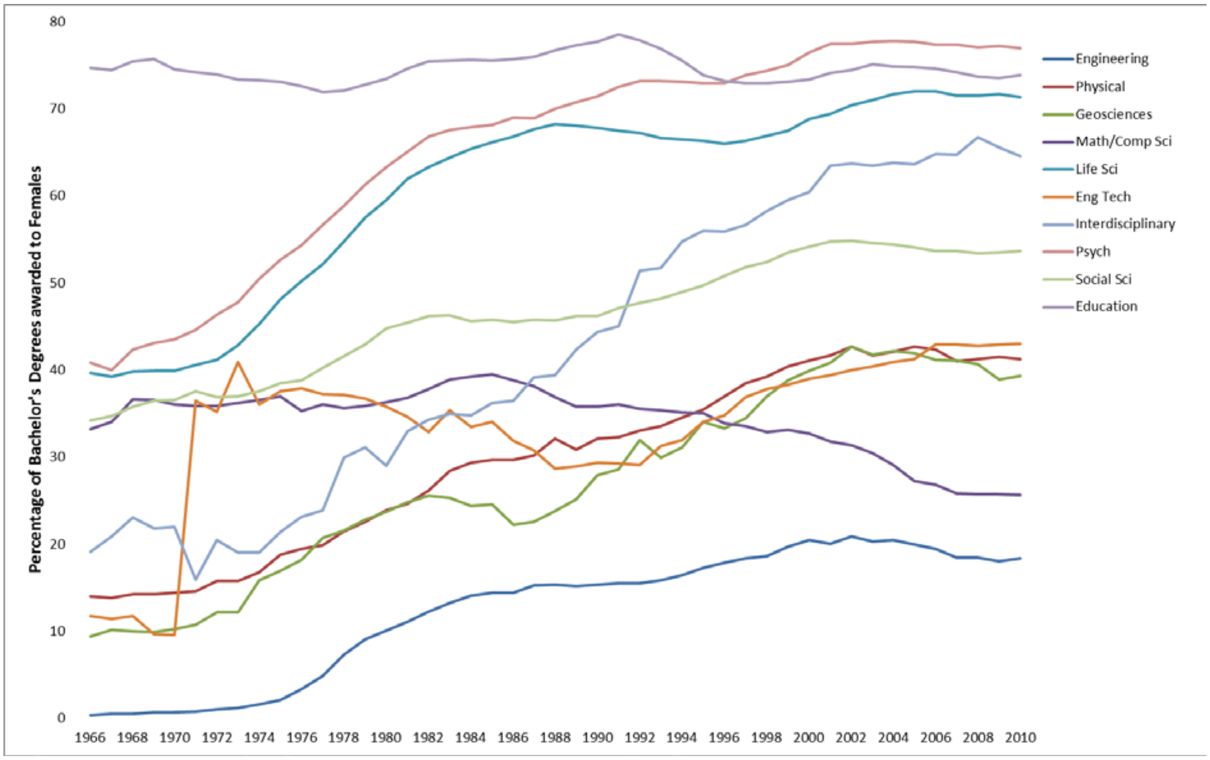
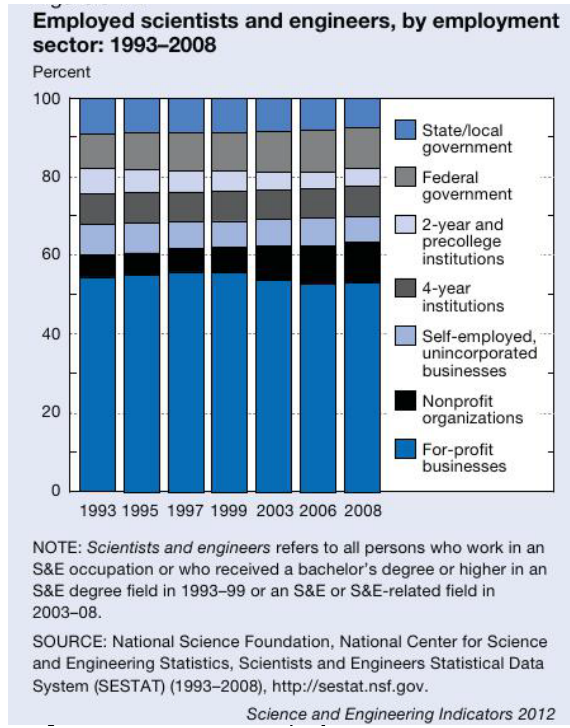


Figure 2.11. Percentage of Bachelor's degrees awarded to females in various STEM and non-STEM fields from 1966-2010. [Source: NCES at WebCASPAR.]

Section 3 Uses of STEM beyond education

For several years, increasing the number of STEM graduates in the U.S. has been repeatedly identified as a goal of substantial significance for U.S. growth and global competitiveness[92]. There is a widespread belief that the U.S. has a shortage of appropriately trained individuals (especially U.S. citizens and permanent residents) to address the research and development needs of the country in the future. In contradiction to this, some have claimed that the U.S., in fact, has a surplus of STEM graduates, which has led to lowered salaries and increased competition for academic and private sector positions[93].



Graduates, from Science & Engineering Indicators (2012).

I. Where STEM graduates go

Figure 3.1, drawn from the *Science and Engineering Indicators 2012* report, shows the trends of employment for 'scientists and engineers' (which includes individuals who received a Bachelor's degree in the sciences or engineering as well as individuals who work in an S&E occupation without such a degree). Minor shifts during the period 1993-2008 away from employment in state and local government and for-profit business have not changed the overall picture: that a majority of scientists and engineers (as defined in this report) work in the for-profit private sector. It is important to note that approximately 20% of scientists and engineers work in some educational capacity (primary, secondary, or tertiary) and, thus, this is considered as a separate sector on its own.

Of a total labor force of over 150 million (155,291,000 in November 2012[94]), the number of scientists and engineers working in the U.S. in 2006 was 15,769,000[95], which is 10.16% of the labor force. Table 3.1 breaks out the number of US-born scientists and engineers who are working in the U.S. thus directly contributing to the American economy, by sector and as a fraction of their total workforce. These numbers are broadly consistent with the aforementioned trends in Figure 3.1. In all, 2/3 were active in business/industry (including for-profit, self-employed, and not-for-profit sub-sectors), 1/8

---

92 Augustine, N. (2005). Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future, Washington, DC: National Academy of Science, National Academy of Engineering, Institute of Medicine, National Academy Press; President's Council of Advisors on Science & Technology. (2012). Engage to Excel: Producing One Million Additional College Graduates with Degrees in STEM. Full report available online at http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-stem-ed-final.pdf.

93 Including: Lowell, B. L. & Salzman, H. (2007). Into the Eye of the Storm: Assessing the Evidence on Science and Engineering Education, Quality, and Workforce Demand. Madison, WI: Association for Public Policy Analysis and Management; Teitelbaum, M. S. (2003). 'Do We Need More Scientists?' The Public Interest: 40–53. Carnevale, Smith, & Melton, (2011). 'STEM', Washington, DC: Georgetown Center for Education and the Workforce, p. 6. Online at http://cew.georgetown.edu/STEM

94 Bureau of Labor Statistics, December 2012, online at http://www.bls.gov/news.release/archives/empsit_12072012.htm

95 Science and Engineering Indicators 2012, p. 3-61, online at http://www.nsf.gov/statistics/seind12/

in government (at all levels), and 1/5 in the education sector (all levels). With respect to the size of the economic sector, US-born scientists represent 1/8 of the business/industry workforce, only 9% of the people working in government, but almost 40% of the people working in education[96,97].

Table 3.1. The breakdown of US-born scientists and engineers on US economic sectors and sub-sectors.

Sector	**Total employment**	**Percentage of US-born STEM workforce**	**Percentage of sector represented by STEM**
Business/industry	10,484,000	66.5	12.8
Government	2,012,000	12.8	08.9
Education	3,273,000	20.8	38.9
Four-year institutions	*1,320,000*	*8.4*	
Other schools	*1,954,000*	*12.4*	
Total S&E	15,770,000	100.1 (rounding error)	-

Taken another way, it is instructive to break down the Science & Engineering labor force according to the NSF's S&E, S&E-related, and non-S&E-related occupations (Table 3.2). Scientists and engineers working in S&E occupations, likely those with the highest educational attainment, make up less than a quarter of the total, with the largest constituencies being computer/mathematical scientists (9.2 % of employees) and engineers (7.2%). An additional 30% of the total scientists and engineers work in S&E related occupations, while the rest, almost half of the total, have diverted to non S&E occupations altogether.

Table 3.2. The breakdown of US-born scientists and engineers in US occupations.

Occupation	**Total employment**	**Percentage of US-born STEM workforce**
S&E occupations	3,608,000	22.9
Computer/mathematical scientists	*1,445,000*	*9.2*
Biological/agricultural/other life scientists	*371,000*	*2.4*
Physical scientists	*254,000*	*1.6*
Social scientists	*400,000*	*2.5*
Engineers	*1,138,000*	*7.2*
S&E related occupations	4,852,000	30.8
Non S&E related occupations	7,309,000	46.4
Total S&E	15,770,000	100.1 (rounding error)

In Tables 3.1 and 3.2, the values quoted are for US-born STEM scientists and engineers. This reflects a longstanding focus on natural-born American citizens, arising from a concern about the role that immigrants play in the workforce generally, and in the STEM workforce specifically.[98] An unsettled debate is over the effects that immigrants have on STEM labor markets: some have argued that there are long-term benefits (in terms of productivity and wealth generation) to all workers, while others ‘claim that immigration drives down wages and take jobs that would have otherwise been filled by

96 Bureau of Labor Statistics, Employment by major industry sector, http://www.bls.gov/emp/ep_table_201.htm

97 Bureau of Labor Statistics, Occupational employment and wages, 2011, www.bls.gov/news.release/archives/ocwage_03272012.pdf

98 See, for example, Carnevale, Smith, & Melton, (2011). ‘STEM’, Washington, DC: Georgetown Center for Education and the Workforce, Online at http://cew.georgetown.edu/STEM. Borjas, G. J. (2006); ‘Immigration in High-Skill Labor Markets: The Impact of Foreign Students on the Earnings of Doctorates’. National Bureau of Economic Research, Working Paper 12085. Online at http://www.nber.org/papers/w12085.

native-born workers.'[99] One particularly well-known program that has come under much scrutiny is the H1-B visa program, which uses a lottery system to allot visas to highly-trained and highly-skilled workers, often those in STEM.[100] Policy makers have responded by focusing on US-born individuals in discussions of the STEM workforce. We discuss immigration-related considerations more in Section 4.

II. STEM skills and knowledge required by labor market

Analysis of the O*NET occupational database reveals a set of competencies, both cognitive and non-cognitive, that are associated to STEM occupations and are transferable to other occupations[101]. The cognitive competencies are outlined in Table 3.3. The set of cognitive competencies is divided into three sections: domain knowledge, core skills (relating to content, procedures, and problem solving), and more-broadly defined abilities (seen as enduring and developed personal attributes that influence performance in the workplace). The core competencies associated with STEM are also in demand in non-STEM occupations, which creates the conditions for potentially diverting part of the STEM workforce outside of STEM.

Table 3.3. Cognitive competencies associated with STEM occupations.

STEM knowledge domains	STEM core skills	Abilities associated with STEM occupations
Production and processing	Mathematics	Problem sensitivity
Computers and electronics	Science	Deductive reasoning
Engineering and technology	Critical thinking	Inductive reasoning
Design	Active learning	Mathematical reasoning
Building and construction	Complex problem solving	Number facility
Mechanical	Operations analysis	Perceptual speed
Mathematics	Technology design	Control precision
Physics	Equipment selection	
Chemistry	Programming	
Biology	Quality control analysis	
	Operations monitoring	
	Operation and control	
	Equipment maintenance	
	Troubleshooting	
	Repairing	
	Systems analysis	
	Systems evaluation	

To understand the large number of graduates who have the skills associated with STEM occupations but choose not to pursue STEM careers, note that non-cognitive competencies such as work values (achievement, independence, recognition) and work interests (realistic and investigative) associated with STEM trained individuals are relevant for some non-STEM occupations, thus potentially diverting them outside STEM[102].

III. Shortage vs. oversupply of STEM human capital

99 Carnevale, Smith, & Melton, (2011). 'STEM', Washington, DC: Georgetown Center for Education and the Workforce, p. 73, Online at http://cew.georgetown.edu/STEM.

100 Donnelly, P. (2002). 'H-1B Is Just Another Gov't. Subsidy'. Online at http://www.computerworld.com/s/article/72848/H_1B_Is_Just_Another_Gov_t._Subsidy?taxonomyId=010.

101 Carnevale, Smith, & Melton, (2011). 'STEM', Washington, DC: Georgetown Center for Education and the Workforce, http://cew.georgetown.edu/STEM

102 The list of O*NET work values can be found online at http://www.onetonline.org/find/descriptor/browse/Work_Values/

The issue of shortage or oversupply of STEM human capital has generated some debate[103]. While a comparative look at the number of STEM graduates and the number of STEM job vacancies suggests a balance between supply and demand, a closer inspection of these data reveals structural imbalances on several accounts[104]. First, most STEM job vacancies require a lower level of competency than that generally provided by a Bachelor's degree, thus technician openings are experiencing a large shortage of applicants, while positions requiring high level skills, at the Bachelor's and graduate levels, are much more competitive. Second, STEM skills are not only needed in STEM occupations, but in other economic sectors as well. Given both the competitiveness of obtaining employment in some of the highly specialized STEM occupations, and the transferability of STEM competencies to other categories of occupations, it seems that part of the STEM workforce diverts into non-STEM – fulfilling demand in those fields, especially when wages offered are higher than in STEM occupations. Even in non-STEM fields, STEM degree holders earn more on average than non-STEM degree holders. Also, men and women have different reasons for diverting from STEM: while for men, pay and promotion opportunities play the first role, for women, family-related reasons and working conditions are more important. Given this process of diversion and the economy as a whole demanding workers with STEM skills, a picture emerges of a shortage in the available workforce having STEM-related competencies. Third, the demographic profiles of most STEM occupations do not reflect the gender, racial/ethnic, and socio-economic make-up of the U.S. population, a mismatch that further complicates the picture of supply and demand. One way in which the U.S. economy consistently fills the gaps in needed qualified workforce is via immigration, through which skilled foreign-born STEM workers offer an alternative for meeting employer demands.

IV. STEM skilled individuals' importance in the workforce, STEM fields and other fields

There are some professions that use combinations of knowledge and skills explicitly from STEM training, such as science writers or scientific equipment sales representatives, who are at the interface of STEM and STEM-related domains. There are other professions, especially at the executive level, which benefit from higher-level analytical thinking skills that the study of STEM develops and relies upon. There is even data indicating an advantage for STEM-trained individuals in applications to law school[105].

In the context of global technological advances, the diffusion of technology occurs across industries and, as a consequence, more STEM skills are now needed in virtually every profession. While innovation is at the heart of increases in productivity and wealth - much of it in the form of STEM innovation - in a developed economy, the impact of STEM innovation is felt everywhere. For example, the insurance industry relies on highly-skilled quantitative analysts – actuaries; in the past two decades the finance industry could not be understood without quantitative models that even earned a Nobel

---

[103] For example, Lowell, B. L. & Salzman, H. (2007). Into the Eye of the Storm: Assessing the Evidence on Science and Engineering Education, Quality, and Workforce Demand. Madison, WI: Association for Public Policy Analysis and Management; Teitelbaum, M. S. (2003). 'Do We Need More Scientists?' The Public Interest: 40–53.

[104] Carnevale, Smith, & Melton, (2011). 'STEM' (p. 41), Washington, DC: Georgetown Center for Education and the Workforce, http://cew.georgetown.edu/STEM

[105] AIP report available online at http://www.aip.org/statistics/trends/reports/mcat2009.pdf

Prize[106]. Even fields such as professional sports have been impacted, in that competitive clubs rely in recruiting or retaining athletes decisions on information provided by statisticians (in baseball, called sabermetricians[107]), which disaggregates personal contributions of individual players from a team's performance in order to predict future performance[108]. Similar insights are even suggested to be applied in healthcare management[109].

The employment outlook for the next decade, provided by the Bureau of Labor Statistics, projects high percentage increases for healthcare (29%), personal care and service (27%), and community and social service (24%) occupational groups, and also robust growth for computer and information technology (22%), math (17%), and life, physical and social sciences (16%)[110,111]. With respect to educational attainment, the highest growth is estimated for professions requiring Master's (22%), doctoral (20%), and Associate's degree (18%). Taking into account experiential factors, the predicted increase in demand for holders of doctoral or professional degrees is 23.4% for those with internship or residence training (18.9% for those without training), while the demand for Associate's degree holders with no experience is predicted to increase by 23.7%[112]. While these projections do not give much detail on STEM jobs, but another set of employment projections made by the U.S. Department of Commerce estimate the job growth in STEM occupations to be almost twice that of non-STEM occupations[113]. However, these numbers do not give insights on the extent to which STEM skills will be used in non-STEM occupations.

Considering that the future demand for STEM-trained workforce would be strong for Associate's, Doctoral, and IT Bachelor's degree holders, we propose a framework for understanding the STEM assimilation process at all three levels, as follows:

- Whenever an occupational field undergoes dramatic changes due to the need for acquisition of substantial STEM knowledge, it is the highly-skilled *reformers*, or game-changers, who are the agents of change.
- In normal work settings, a non-STEM employee encountering technological issues generally resorts to coworkers with expertise – engineers, computer specialists, or simply other non-STEM workers with STEM skills relevant for the issue encountered, whether these *'candle in the dark'* experts have a STEM degree or not.
- The steadily rising technological baseline of day-to-day activities, including school work and typical work-related tasks, requires a higher level of STEM skills from everyone over time. The transition to a more technology-intensive economy in the 21st century has raised the bar of entry in most professions, and now jobs which used to be available for high school graduates require

---

106 http://www.nobelprize.org/nobel_prizes/economics/laureates/1997/press.html

107 This name comes from S.A.B.R., Society for American Baseball Research.

108 Nate Silver, The Signal and the Noise: Why So Many Predictions Fail—but Some Don't, The Penguin Press, 2012, ISBN 9781594204111

109 Billy Beane, Newt Gingrich, John Kerry, 'How to Take American Health Care From Worst to First', New York Times, October 2008, available online at http://www.nytimes.com/2008/10/24/opinion/24beane.html

110 T. Alan Lacey and Benjamin Wright, *Occupational Employment Projections to 2018*, Monthly Labor Review, November 2009, online at http://www.bls.gov/opub/mlr/2009/11/art5exc.htm

111 Bureau of Labor Statistics, U.S. Department of Labor, *Occupational Outlook Handbook, 2012-13 Edition*, Projections Overview, online at http://www.bls.gov/ooh/about/projections-overview.htm

112 Dixie Sommers and Teresa L. Morisi, *Employment Projections Through the Lens of Education and Training*, Monthly Labor Review, April 2012, online at http://www.bls.gov/opub/mlr/2012/04/art2exc.htm

113 U. S. Department of Commerce, Economics and Statistics Administration, *STEM: Good Jobs and for the Future*, July 2011, online at http://www.esa.doc.gov/Reports/stem-good-jobs-now-and-future

skills at the level of a professional certificate or an Associate's degree in STEM. This applies to the entire workforce, in a sense the entire workforce is increasingly made of *technicians*.

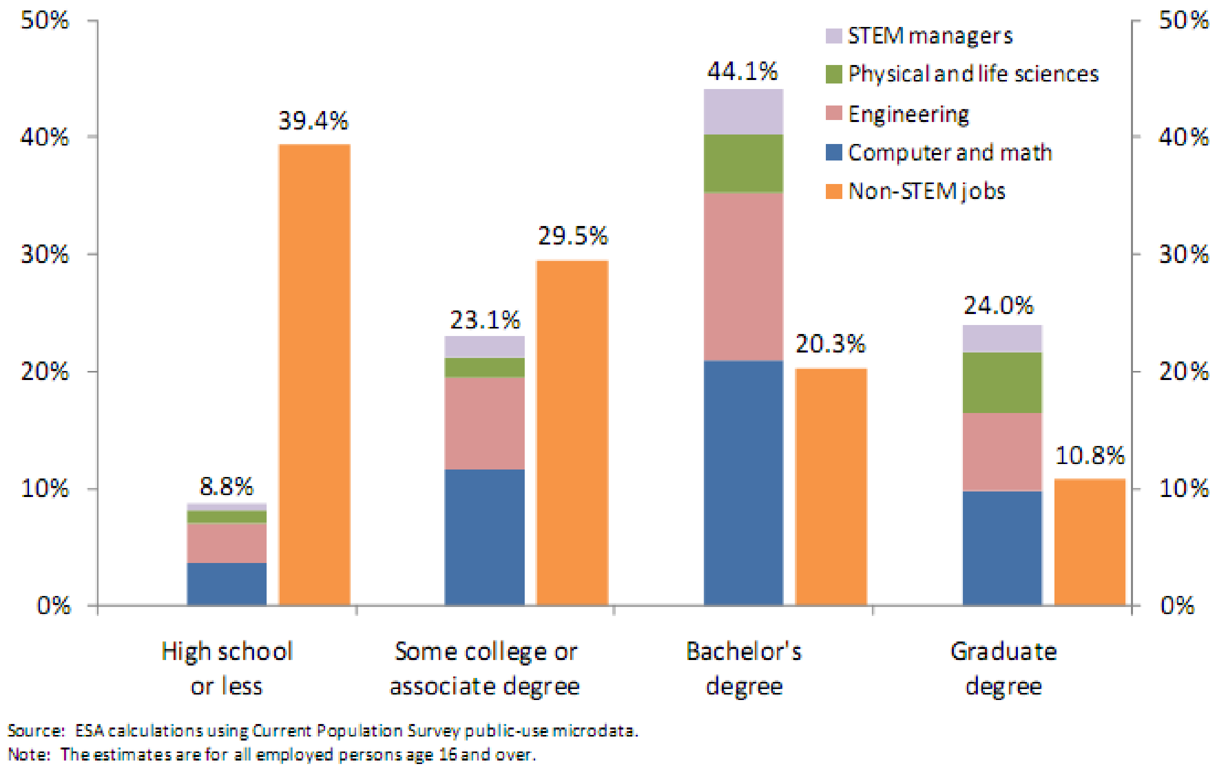


Figure 3.3. The STEM and non-STEM employment distribution by educational attainment [Source: STEM: Good Jobs and For the Future (2011)[114]]

Data in Figure 3.3 suggest potential resources for recruiting STEM technicians: individuals with high school diplomas and some college coursework or Associate's degrees. The advantages of earning STEM degrees for future employment in STEM or in non-STEM occupations (e.g., more jobs, higher wages) should become evident for candidates especially when they can communicate directly with employers, as in the case of partnership programs between companies and community colleges[115] or experience firsthand the activities involved in STEM careers through internships[116].

Beyond the job demands, STEM-related skills are increasingly adaptive in the modern world. As Professor Richard Larson from M.I.T. says:

> A person has STEM literacy if she can understand the world around her in a logical way guided by the principals of scientific thought. A STEM-literate person can think for herself. She asks critical questions. She can form hypotheses and seek data to confirm or deny them. She sees the beauty and complexity in nature and seeks to

---

114 Available here: http://www.esa.doc.gov/Reports/stem-good-jobs-now-and-future

115 The *Skills for America's Future* initiative is discussed in the next section.

116 A description of a recent such initiative can be found online at http://news.sciencemag.org/scienceinsider/2011/09/us-firms-pledge-more-engineering.html

> understand. She sees the modern world that mankind has created and hopes to use her STEM-related skills and knowledge to improve it.[117]

These skills, often developed from STEM courses, are sought by employers in most sectors, making STEM students highly marketable, while at the same time giving those with advanced technical training a number of career options outside of STEM fields.

Section 4

Strategies, policies and programs

Recent legislation impacting the STEM workforce

America COMPETES Act

In 2007, President Bush signed into law the America COMPETES Act[118], which was reauthorized by President Obama in 2010[119]. Generally, this Act seeks to support and stimulate research and development and foster innovation in STEM and in STEM education. Much of this takes the form of appropriations for funding initiatives to award grants considered high-risk/high-reward in areas of critical importance to the US. In terms of education, the Act: a) lays the groundwork for establishing programs to increase the number of STEM teachers and to increase the number of 'qualified' teachers - by 700,000 - serving in high-needs areas who can teach advanced courses in STEM; b) requests coordination of efforts across scientific agencies (e.g., NASA, NOAA, NSF) to promote and improve STEM education; c) suggests that schools observe a national day of STEM; d) calls for a report on promising practices in K-12 STEM teaching and on how to increase the number and performance of underrepresented students in STEM.

One of the initiatives specified is Teachers for a Competitive Tomorrow (TCT). The intent of this program is to increase the number of individuals qualified to teach in areas of critical need, particularly in science and mathematics. TCT attempts to do this by funding the development of Bachelor's and Master's degree programs that combine both STEM content knowledge and teacher certification.

The Reauthorization of this act took place in 2010, which continued many elements of the prior bill while adding some new aspects. This requires the Director of the Office of Science and Technology Policy (OSTP) to establish a committee responsible for coordinating federal efforts related to STEM education. Probably the most important task for this committee is the directive to:

> develop, implement through the participating agencies, and update once every 5 years a 5-year STEM education strategic plan, which shall
>
> (A) specify and prioritize annual and long-term objectives;
> (B) specify the common metrics that will be used to assess progress toward achieving the objectives;

---

117 Richard Larson, 'STEM is for everyone', online at http://www.wise-qatar.org/content/dr-larson-stem-everyone

118 Full text available here: http://thomas.loc.gov/cgi-bin/bdquery/z?d110:h.r.02272:

119 Full text available here: http://thomas.loc.gov/cgi-bin/bdquery/z?d111:hr5116:

(C) describe the approaches that will be taken by each participating agency to assess the effectiveness of its STEM education programs and activities; and

(D) … describe the role of each agency in supporting programs and activities designed to achieve the objectives.[120]

The Director of OSTP is to report to Congress each year on progress toward the strategic plan.

As part of the Reauthorization, NASA and NOAA were specifically directed to increase their efforts to improve student interest in STEM. All agencies are required to promote participation of underrepresented minorities in STEM. There is a large focus on manufacturing and technical education in the original COMPETES Act and in the Reauthorization, where there is a focus on developing programs that use cyber-learning tools to train or retrain the STEM workforce. It also continues the TCT program and provides grants to promote alignment between high school graduation requirements and national needs in STEM. However, recent federal budget problems have meant that the funding for some of these programs has been cut[121].

Interestingly, the Reauthorization also repeals some programs through the Department of Energy that were directed toward making education resources available online, for establishing pre-university internships for pre-university student and for expanding specialty schools in science and mathematics. It also repeals the directive for the National Academy of Sciences to produce a report on promising practices in K-12 and some of the funding opportunities for school districts to improve their math programs.

Beyond education, as part of the Reauthorization, Federal agencies were granted the ability to hold prize-based competitions in certain areas to spark innovation. The Reauthorization also established the National Center for Science and Engineering Statistics, as part of NSF, to collect and disseminate data on STEM research, development, and education.

Federal funding of K-12

Given that funding, and the 'strings' associated with securing it, is the main tool the federal government uses to reform education in the US, it is not surprising that recent legislative efforts to influence STEM education are tied to federal dollars. Federal funding of education generally makes up approximately 10% of total funding in the US[122]. In 2010, this proportion was slightly increased to 12.5% ($74 Billion) as part of a broad stimulus package initiated by the government as an effort to stimulate economic growth[123]. Of course, only a fraction of the nearly $600 Billion spent on education is directed toward improving STEM education. At the federal level, this funding comes from a variety of programs through a number of key agencies including the Department of Education (~$520 M), and other agencies with STEM-related missions, including the National Science Foundation, the National Aeronautics and Space Administration (Table

120 Text quoted from: http://thomas.loc.gov/cgi-bin/query/F?c111:6:./temp/~c111HJcTu7:e8284:

121 Information retrieved from: http://www2.ed.gov/about/offices/list/ope/2011-program-budget.html

122 Government Accountability Office. (2010). Federal Education Funding: Overview of K-12 and Early Childhood Education Programs. Report available here: http://www.gao.gov/products/GAO-10-51

123 U.S. Census Bureau. (2012). *Public Education Finances, 2010.* Washington, DC: U.S. Census Bureau. Retrieved from: http://www2.census.gov/govs/school/10f33pub.pdf

4.1[124]). While a comprehensive review of each agency and their funding for STEM education is beyond the scope of this report (a general view is provided in Appendix A), the main message put forth by the authors of the 2010 PCAST report was that these efforts should be increased and better coordinated to maximize the potential for research and development toward improving STEM education.

Visa policies regarding STEM students and professionals

Student visas: PhD graduates can remain legally and work in the US for up to 12 months beyond graduation on the nonimmigrant F1 status. As recently as 2007, for certain STEM fields this period has been extended to 29 months. As of 2011, the list of disciplines eligible for this extension has been expanded[125].

Employment-based visas: Under the provisions of American Competitiveness in the Twenty-First Century Act of 2000[126], annually up to 65,000 H-1B visas are issued to foreign nationals sponsored by US companies. Additionally, each year up to 20,000 foreign nationals with graduate degrees from US universities can be issued H-1B visas. Foreign nationals working in universities and non-profit or governmental research facilities are issued H-1B visas in addition to the first two categories. The H-1B is a dual-intent visa; the employer can file on employees' behalf for permanent residence, the first step toward naturalization.

---

[124] Table and notes based on Table 3-2 from PCAST (2010) p. 29

[125] Online at http://news.sciencemag.org/scienceinsider/2011/05/us-broadens-job-prospects-for-fo.html

[126] Online at http://www.uscis.gov/ilink/docView/PUBLAW/HTML/PUBLAW/0-0-0-22204.html

Table 4.1. Science mission agency funding for K-12 STEM education, teachers, and outreach (estimated).

Agency	FY10 Funding ($MM)	FY11 Budget Request ($MM)
National Science Foundation	$458.3	$453.7
National Aeronautics and Space Administration	$87.8	$89.5
Department of Health and Human Services / National Institutes of Health	$45.8	$43.7
Department of Commerce (incl. National Institute of Standards and Technology, National Oceanic and Atmospheric Administration)	$40.1	$32.2
Department of Defense	$22.9	$23.6
Department of Energy	$11.1	$26.5
Environmental Protection Agency	$3.4	$3.6
US Department of Agriculture	$1.5	$4.0
Department of Transportation	$1.25	$1.25
National Security Agency	$0.4	$0
TOTAL	$672.60	$678.1

Notes. 1. In response to a PCAST request, Office of Manaement and Budget requested data from Federal agencies on their STEM Education programs. These data were then collected in a central database by the Science and Technology Policy Institute (STPI) and expanded with additional information on the purpose of each of the STEM programs. For this report, PCAST analyzed data in the central database. 2. Agency total for STEM education does not include funding from the U.S. Department of Labor, which targets primarily workforce training through the Employment and Training Administration for those older than age 16. (These funds total over $5.4 billion in FY10 funding plus $4 billion in FY09 American Recovery and Reinvestment Act funding.) The inventory identified no funded K-12 outreach or informal education programs in the Department of Interior or Department of Homeland Security.

STEM Jobs Act Initiatives with impact on immigration policies: In the past two years, several legislative initiatives were discussed[127]. While the two of them introduced in 2011 in the House of Representatives did not get the committees' approval, the SMART Jobs Act initiative, later renamed STEM Jobs Act, co-sponsored by senators Lamar Smith and Chris Coons was approved in December 2012 by the House of Representatives by a margin of 245 to 139[128] only to be blocked a few days later by the Senate Democrats[129]. The final form of STEM Jobs Act proposed the reallocation of immigrant visas from the Diversity program (popularly known as the Visa Lottery) to highly qualified foreign graduates of American graduates with advanced degrees in STEM fields. Earlier in 2012, another legislative initiative, called the STAR Act, sponsored by Senator John Cornyn, stipulated that STEM graduates working in institutions receiving at least $5 million a year in federal research grants could be granted permanent residence. The legislative project was referred to the House committees, but was not enacted.

127 Online at http://news.sciencemag.org/scienceinsider/2012/05/senate-dips-toe-into-stem-immigr.html
128 Online at http://news.sciencemag.org/scienceinsider/2012/12/vote-on-divisive-immigration-bil.html
129 Online at http://judiciary.house.gov/news/12052012.html

Strategic documents and initiatives

Policy reports recommending strategies

In the past decade, several STEM policy reports have been released, with a goal of informing the future actions of governmental institutions ranging from state governors, to Congress and the US President. We present here the most relevant of these reports, commenting on the specific context in which they were elaborated, the direction of focus the reports suggest, and the character of the suggested focus in different periods in time.

Several conclusions can be drawn by reading the various policy reports on STEM presented here. First, while the picture drawn in earlier reports is more general, spanning several sectors, the tendency for the later ones is to go into greater detail in one sector (e.g., education, enterprise). Further, the educational system is, in later reports, broken down into K-12, college, graduate school, and post-graduation. This is important, because this specificity comes at the price of not considering explicitly all the interdependences between sections addressed separately. Second, as the magnitude of the challenges posed by the globalized 21st century economy becomes more apparent, the magnitude of the desired change (measured in number of teachers or students targeted) increases accordingly. Third, the importance of inquiry-based learning strategies in education goes from being no more than a footnote in early reports to a playing a central role in later ones. Fourth, each institution releasing STEM reports emphasizes certain aspects of the whole picture (accompanied by specific recommendations and concrete actions), and most of them have: a) a systemic approach in that they envision a structure connecting all interested stakeholders; b) a decision chain coupled with a funding scheme; and c) a feedback path aimed to record and interpret progress of the strategy implementation, and adjust accordingly to the new factors encountered in the process. Fifth, transitions are not continuous. Sometimes there are initiatives which were not implemented and yet are raised as recommendations in later reports, while at other times initiatives are implemented in a different form than initially planned (e.g., the Presidential Council on STEM Education, whose creation is recommended in the February 2012 'Engage to Excel' report[130]).

Rising Above the Gathering Storm (2005)[131]

Following bipartisan letters from the US Senate and House Committee on Science, the National Academies' Committee on Science, Education, and Public Policy (COSEPUP) created the Committee on Prospering in the Global Economy of the 21st Century: An Agenda for American Science and Technology[132]. Members included presidents of major universities, Nobel laureates, and CEOs of Fortune 100 corporations. COSEPUP was charged to identify the top 10 actions, in priority order, for federal policymakers to enhance science and technology enterprise so the US could successfully compete, prosper, and be secure in the 21st century global community; and to elaborate an implementation strategy, containing several concrete steps, for each action. Based on previously issued papers, COSEPUP assembled four recommendations and the actions

130 Not to be confused with the NSTC Committee on STEM Education, created following the America Competes Reauthorization Act of 2010, or with the Presidential Council of Advisors on Science and Technology – PCAST.
131 Report available here: http://www.nap.edu/openbook.php?isbn=0309100399
132 Online at http://www.nap.edu/catalog.php?record_id=11463

needed to implement these recommendations, actions which were collected from focus groups consisting of experts in K-12 education, higher education, research, innovation and workforce issues, and national and homeland security.

The final report describes key elements necessary to achieve American prosperity in the 21st century, and how science and technology is critical to this prosperity. The report evaluates the current status of science and technology and provides recommendations for improving American prosperity. Finally, the report describes the status of U.S. prosperity in three future scenarios: narrow lead, falling behind, and emerging as the leader.

The recommendations are prefaced with the presentation of two key challenges coupled to science and engineering prowess: creating high quality jobs for Americans, and responding to the national need for clean, affordable energy. These challenges create the premises for four urgent and very urgent recommendations on human, financial, and knowledge capital needed for US prosperity, and 20 concrete actions to implement them, rather than the 10 the committee was initially tasked with. The recommendations and their corresponding actions would require changes to existing laws, as well as funds, either new or obtained through reallocation of existing funds.

From the perspective of the impact on the STEM workforce, the recommendations and actions identified in the report are either directly or indirectly relevant (see Table 4.2 for the recommendations). Directly relevant are: Recommendation A, which focuses on the multiplicative effect of well-prepared science and mathematics teachers on their students; and Recommendation C, which proposes to attract the brightest people into STEM, from the national talent pool (by offering competitive undergraduate scholarships and graduate fellowships, as well as tax credits to companies encouraging their employees' continuous education) as well as from the international talent pool (by facilitating access to education, employment, visa processing, and skill-based immigration, especially in the context of tightening scrutiny on foreign individuals entering US after 9/11). Measures indirectly impacting the STEM workforce by fostering innovation are: Recommendation B, focused on funding research and innovation, with emphasis on basic research; and Recommendation D, which seeks to incentivize innovation, which in turn will impact manufacturing and marketing, including the creation of jobs in these fields, traditionally categorized as non-STEM.

Table 4.2.
Recommendations and actions included in the 'Rising Above the Rising Storm' report

A. **Increase America's talent pool** by vastly improving K-12 science and mathematics education A1. Annually recruit 10,000 science and mathematics teachers by awarding 4-year scholarships and thereby educating 10 million minds A2. Strengthen the skills of 250,000 teachers through training and education programs at summer institutes, in Master's programs, and AP/IB training programs and thus inspire the skills of 250,000 students every day. Also make available world-class standards K-12 curricular materials A3. Enlarge the STEM pipeline by increasing the number of AP/IB science and math course taking. Even students who took AP/IB courses but did not pass exam had high TIMSS scores Additional approaches include: statewide specialty high schools to provide intense immersive learning experience for best students, and inquiry-based learning to stimulate student interest and achievement, including low-income and minority students. B. **Sowing the seeds** through science, engineering, and research: Sustain and strengthen the nation's traditional commitment to the long-term research that has the potential to be transformational to maintain the flow of new ideas that fuel the economy, provide security, and enhance the quality of life. B1. Funding for basic research: given the inadequate funding of research, the report proposes increases in federal research funding, justified by the results expected to be delivered. B2. Establishment of a program to provide 200 new research grants of $500,000 each year, payable over 5 years, to support the work of outstanding early career researchers in universities and government laboratories, through federal agencies (NIH, NSF, DOD, DOE, NASA). B3. Establishment of a National Coordination Office for Research infrastructure, to manage a fund of $500 million per year over the next 5 years, which will support construction and maintenance of research facilities. Funding should become available either through reallocation of existing funds, or via new funds, and universities and governmental national labs should compete annually for the funds. B4. At least 8% of the federal research agencies' budgets should be directed to high-risk, high-payoff research. B5. Creation of a Department of Energy organization to sponsor programs for meeting the nation's long-term energy needs. C. **Best and brightest** in science and engineering higher education: Make the United States the most attractive setting in which to study and perform research, so that we can develop, recruit, and retain the best and brightest students, scientists, and engineers from within the United States and throughout the world. C1-C2: Increase the number of US citizens with STEM bachelor and higher degrees by providing 25,000 new competitive 4-year undergraduate scholarships and 5000 new graduate fellowships awarded each year. C3. Provide tax credits, up to $500 million annually, to employers helping eligible employees to pursue continuing education. C4-C8: Revise visa-granting, immigration policies, funding procedures, and provide access to technical information and equipment to allow outstanding international students and scholars to the US research and innovation enterprise. D. **Provide incentives for innovation** as a way to invest in downstream activities such as manufacturing and marketing; create new high-paying jobs based on innovation by modernizing the patent system, adjusting the tax system, ensuring affordable broadband internet access.

The report also spells out some of the challenges faced by the STEM sector. It currently relies on international students and workers to fill open jobs due to a lack of a natural constituency for science. Teachers are ill-prepared: a large proportion of K-12 STEM teachers did not minor, major, or earn a certificate in the discipline taught. Students are characterized by a large diversity and there exists a large variation of quality between schools, districts, and suburban, urban and rural settings. A lack of interest in STEM disciplines is manifest, and students do not learn in schools the prerequisites for learning sciences, beginning in middle school. Gatekeeper introductory science courses thus effectively weed out many students who initially intended to study STEM. Those who graduate face tenuous local career prospects given the offshoring of jobs. Also, in knowledge-intensive professions, it is harder to stay current.

National Actions Plan for Addressing the Critical Needs for the U.S. Science, Technology, Engineering, and Mathematics Education System (October 2007)[133]

The National Science Board's (NSB) proposals focus on the construction of a strong, coherent, national STEM education system. From this perspective, the challenges encountered are split between ensuring the coherence of STEM learning and ensuring an adequate supply of well-prepared, highly-effective STEM teachers.

Recommendations in the proposal fall into four broad categories, as follows:

- Creation of three new structures with the role of coordinating national STEM initiatives and informing policymakers and the public: one independent, National Council for STEM Education, another one with the President's Office of Science and Technology Policy, and a third one in the Department of Education, led by a new Assistant Secretary of Education who will coordinate STEM education efforts. Another recommendation is for the National Science Foundation to create a roadmap to improve STEM education from pre-kindergarten to college.

- Provision of **horizontal coordination** of STEM education by all stakeholders by elaborating a strategy to define national STEM content guidelines outlining the essential knowledge and skills needed at each level; by developing metrics used in the student performance aligned with the proposed guidelines; by ensuring that assessments mandated under the No Child Left Behind Act promote STEM learning; and by sharing and disseminating information and best practices in STEM teaching and learning.

- Promotion of **vertical alignment** of STEM education across grade levels, by improving the linkage between high school, higher education, and workforce; by creating or strengthening STEM education councils in each state; and by encouraging alignment of STEM content throughout the P-12 education system.

- Strategies for boosting the number and expertise of **well-prepared and highly-effective STEM teachers**: market rate compensations for STEM teachers, resources for preparing future STEM teachers, creation of national STEM teacher certification standard to increase teacher mobility, and preparing STEM teachers to teach STEM content effectively.

National Science Board STEM education recommendations for the President-Elect Obama administration (January 2009)[134]

---

133 Report available here: http://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsb07114

The National Science Board sent a list of recommendations for actions to then President-Elect Obama's administration. The recommendations to advance STEM education for all American students, nurture education, and ensure long-term prosperity were to be implemented starting in early 2009, and constitute, in the view of the authors, the essential components of an effective STEM education system:

- A **motivated public, students, and parents**: public awareness campaigns emphasizing the importance of a solid education, especially in STEM; appeal to parents to understand this need and use their influence at home, in school and community to bring about positive changes; encourage coalitions among the interested stakeholders.

- **Clear educational goals and assessments**: to replace the large variability and lack of consistency across states and school districts: articulate the core concepts and skills required from all students, while taking into account variability in student learning styles; help the development of assessments that promote STEM learning and encourage critical thinking, communication, and problem-solving skills; ensure the development of talents of all children with the potential to become STEM innovators.

- **High-quality teachers**: allocate resources for STEM teachers' appropriate pay; continue support for programs helping prepare STEM undergraduate majors and professionals to become K-12 teachers in neediest schools.

- **World-class resources and assistance for teachers**: a federal initiative to examine the best ways to use advanced technology in education; establishment of a Science Corps, made up of active and retired STEM professionals, to assist teachers in classroom, school, district and summer and after-school programs; creation of web-accessible resources of validated STEM instructional materials and best practices, including some developed in other countries; development of a web resource compiling research from cognitive sciences and STEM education fields that is relevant to educational practice; increase of funding for research on learning and STEM teaching.

- **Early start in science**: include STEM core concepts in early education programs; improvement of the extent and quality of elementary school STEM education; exercise of Presidential leadership in motivating parents and other community members to support these goals.

- **Communication, coordination, and collaboration**: encouragement and funding of coalitions (between K-12 school systems, 2- and 4-year colleges and universities, informal science education organizations, business and industry) addressing STEM education issues; streamline ways for the Federal Government to coordinate STEM education research and disseminate successful STEM education al activities to state and local agencies.

---

[134] Document available online at www.nsf.gov/**nsb**/publications/2009/01_10_**stem**_rec_obama.pdf

Successful K-12 STEM Education: Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics (2011)[135]

The National Actions Plan prepared by the National Science Board, discussed earlier, reflects the results of a larger effort on STEM education. The initial charge was to outline criteria for identifying effective STEM schools and programs. The report shifts the focus from institutions to teaching practices; in other words, 'it's instruction, not schools'[136] that makes the difference for students. Effective STEM instruction, from the perspective of the report's authors, 'capitalizes on students' early interest and experiences, identifies and builds on what they know, and provides them with experiences to engage them in the practices of science and sustain their interest'[137].

Building a Science, Technology, Engineering, and Math Education Agenda (December 2011)[138]

In a report presented by the National Governors' Association, a national STEM agenda is sketched out including goals, its relevance, potential pitfalls, and concrete steps to be taken in order to implement a state level STEM agenda. This STEM agenda is built around two goals: the first is to expand the number of students ready to enter postsecondary study and pursue STEM careers in order to increase the innovative capacity of the U.S. workforce; the second is to improve the basic STEM knowledge of all students as a means for them to be able to assess problems, use STEM concepts and apply creative solutions in their daily lives. Both goals, if achieved, would enhance the competitiveness of the U.S. economy and help individuals achieve economic security in their careers, given that STEM salaries are above the national average, and also because STEM skills are in demand even in non-STEM occupations.

The main obstacles in reaching these objectives are: inconsistent and unclear state standards in math and sciences; a shortfall of qualified math and science classroom teachers many of whom neither majored, minored, nor are certified in the discipline they teach; many students not being adequately prepared for studying STEM in college due to a lack of qualified teachers or due to not having taken sufficiently challenging high school courses or practicing the learned concepts in real-world problems; low student motivation for studying STEM because the disciplines are not taught as connected to other disciplines or with real life with the consequence that students cannot envision a science career as relevant; and the higher education system does not prepare their graduates for what the economy needs.

The report's six steps that states are to take across the entire K-20 curriculum are:

. **Adopt rigorous math and science standards and improved assessments**. In 2009, the Common Core State Standards Initiative released new world-class standards for math and English language, and two years later they were adopted by 46 states. These standards define the knowledge and skills students should acquire in K-12 courses, are evidence based, include rigorous content and application of knowledge, are aligned with college and work expectations, and are informed by

[135] Report available here: www.nap.edu/catalog.php?record_id=13158
[136] Online at http://news.sciencemag.org/scienceinsider/2011/06/report-says-instruction-not-schools.html
[137] Successful K-12 STEM Education, p. 18, online at http://www.nap.edu/catalog.php?record_id=13158
[138] Report available here: http://www.nga.org/files/live/sites/NGA/files/pdf/1112STEMGUIDE.PDF

other top-performing countries standards. For science, a blueprint for the development of state standards is constituted by the ‘A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas’ report[139], from which the standards are currently developed into the Next Generation State Standards[140] by Achieve, a bipartisan, non-profit organization, formed in 1996 at the initiative of a group of governors and corporate leaders. In addition to previous state standards, the new state standards would address both procedural skills and conceptual understanding, and also application to real-world problems. The new universal standards will take several years to implement. The assessments should be changed accordingly, in that they will provide a common and consistent measure of student performance across states, in a pooled effort, at a lower cost for each state.

- **Recruit and retain more qualified and effective teachers**. For this objective to be realized, several policies are recommended. First, the use of financial incentives as recruitment and performance bonuses to attract teachers into hard-to-serve areas or hard-to-place positions. Second, the improvement of institutional conditions in order to promote teacher retention. While math and science teacher salary is correlated with turnover, other actions, such as maintaining discipline, providing strong leadership, requesting teacher input in school-wide decisions, providing some classroom autonomy, and relevant professional development opportunities, influence teacher retention as well.

- **Provide rigorous preparation for STEM students**. STEM-specialized schools can provide students with a college-ready curriculum; most existing schools of this nature are at the high school level. Early college is a variant of high school courses which blend high school and college curriculum, and provide both capacity building and ‘learning outside the school walls’. Online STEM learning, sometimes combined with on-site study, gives students access beyond what they have available in their current school.

- **Use informal learning to expand math and science beyond the classroom**. Expanding classroom teaching strategies with hands-on math and science activities, and organized educational opportunities outside the classroom can promote science learning.

- **Enhance the quality and supply of STEM teachers.** To support the STEM pipeline, more and better prepared teachers will result from enhanced preparation programs and from alternative pathways which allow science and math professionals to enter the teaching profession.
- **Establish goals for postsecondary institutions to meet STEM jobs needs.** Meeting the demand for an educated workforce from businesses can be sanctioned by performance funding using metrics addressing this very issue.

The Competitiveness and Innovative Capacity of the United States (January 2012)[141]

[139] Available online at http://www.nap.edu/catalog.php?record_id=13165
[140] More about the Next Generation Science Standards at http://www.achieve.org/next-generation-science-standards
[141] Available online at http://www.esa.doc.gov/sites/default/files/reports/documents/thecompetitivenessandinnovativecapacityoftheunitedstates.pdf

This report, released by the Department of Commerce and the National Economic Council, is a wider picture of US competitiveness arising from the capacity to innovate in the global economy of the 21st century. In the chapter dedicated to education, the report advocates for the learning of STEM skills at all levels within the educational system, because although STEM jobs have the highest increase rate and some of the highest hourly earnings, two thirds of STEM degree holders work in non-STEM occupations, such as healthcare, education, social sciences, and management. Despite this, several factors concur toward US students not entering STEM fields or, if they start, not continuing them. Among these factors are: poor K-12 math and science preparation, unwillingness to commit additional time needed for STEM courses compared to their non-STEM peers. While women and most racial and ethnic minorities are underrepresented in STEM, foreign-born individuals represent a significant share of STEM workers, especially among those with graduate degrees.

Prepare and Inspire (September 2010) [142]

This report, speaking to the need to motivate students, acknowledges that the focus should be on both preparing all students to be STEM proficient and inspire them to learn STEM. The report also recognizes the need to approach K-12 STEM education in a coherent manner, based on strategy and coordination. The recommendations follow from these two conclusions, as follows:

- **Standards:** acknowledges the state-led advances in developing STEM common standards, and proposes to support these efforts;
- **Teachers:** recruiting and training 100,000 great STEM teachers in the next decade, able to prepare and inspire students;
- **Teachers:** recognize and reward the top 5% of teachers, by creating a STEM Master Teachers Corps;
- **Educational technology:** use technology to drive innovation, by creating ARPA-ED;
- **Students:** create the premises for individual and group inspiring experiences outside the classroom;
- **Schools:** create 1,000 new STEM-focused schools over the next decade;
- **Ensure strong and strategic national leadership.**

Engage to Excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics (February 2012)[143]

The PCAST released this report as an effort to provide a roadmap for increasing the number of STEM professionals by focusing on the first two years of college, seen as critical to retention and recruitment of STEM majors. Besides the improvement of the first two years of STEM education in college, two other imperatives constituted the platform for the suggestions in the report: to provide all students with the tools to excel and to diversify the pathways to STEM degrees. See Table 4.3.

In the context of retention rates in STEM undergraduate programs of 40%, the objective of increasing the number of STEM graduates by one million in a decade, implying a one-

---

142 Full report available online at http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-stem-ed-final.pdf

143 Report available here: http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final_2-25-12.pdf

third increase over the current graduation rate is seen as possible by increasing retention to 50%. Research is cited as a reason to focus, among the factors influencing retention, on intellectual engagement and achievement, motivation, and identification with a STEM field. Identification of these factors leads to corresponding key strategies to increasing retention:

- **Adopt STEM teaching strategies that emphasize student engagement**, in an acknowledgment of the fact that lectures, as a traditional teaching approach, have serious limitations and need to be replaced with activities where students are more active in their learning.
- **Provide all students with the tools to excel** by addressing the prerequisites to STEM study, unevenly acquired by students due to socioeconomic factors (gender, race/ethnicity, income) limiting their access to significant learning experiences before college. The strategy also shifts one of the traditional premises of teaching introductory STEM courses, the focus moving from selecting and retaining only those students who already have the necessary skills and motivation to succeed on their own to a more accessible and personally relevant learning experience.
- **Diversify pathways to STEM degrees**, allowing for a larger diversity in student background, level of preparation, individual pace and style of learning, and concurrent career or family constraints.

Coordinating Federal Science, Technology, Engineering, and Mathematics (STEM) Education Investments: Progress Report (February 2012)[144]

The CoSTEM report, prepared in response to the requirements of the America COMPETES Reauthorization Act of 2010, lays out a 5-year federal STEM education strategic plan including a vision, goals, and objectives. The primary goal is to develop a shared pathway between the 13 federal agencies with roles in STEM education for more effective and efficient investments. The report establishes the federal agencies' STEM education focus on STEM workforce development and on STEM literacy. The STEM workforce goal is to:

> Provide STEM education and training opportunities to prepare a diverse, well-qualified workforce, able to address the mission needs of the Federal agencies and lead in innovation across the broad spectrum of industries and occupations related to the missions of Federal agencies.[145]

The report's literacy and proficiency goal, to increase access and to improve the quality of pre-K-12, post-secondary, and informal STEM education, is translated into five objectives aimed at: increasing STEM interest and engagement among the public of all ages; increasing the opportunities to develop deeper STEM knowledge, skills, and abilities; improving STEM educator and leader preparation; improving the institutional capacity to support effective STEM education and learning programs; and increasing the STEM learning base and use of evidence-based STEM education practices.

Table 4.3. Recommendations and Actions from Engage to Excel Report (2012).

---

144 Report available here: http://www.whitehouse.gov/sites/default/files/microsites/ostp/nstc_federal_stem_education_coordination_report.pdf

145 Quoted from page 11 of report cited in 143.

1. **Catalyze widespread adoption of empirically validated teaching practices**.

1-1. Establish discipline-focused programs funded by Federal research agencies, academic institutions, disciplinary societies, and foundations, to train current and future faculty in evidence-based teaching practices

1-2. Create a 'STEM Institutional Transformation Awards' competitive grants program at NSF

1-3. Request that the National Academies develop metrics to evaluate STEM education

2. **Advocate and provide support for replacing standard laboratory courses with discovery-based research courses**.

2-1. Expand the use of scientific research and engineering design courses in the first years through an NSF program

2-2. Expand opportunities for student research and design in faculty research laboratories by reducing restrictions on Federal research funds and redefining a Department of Education program

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

3-1: Support a national experiment in mathematics undergraduate education at NSF, the Department of Labor, and the Department of Education

4. **Encourage partnerships among stakeholders to diversify pathways to STEM careers**

4-1 Sponsor at the Department of Education summer STEM programs for high school students

4-2 Encourage pathways from 2- to 4-year institutions through an NSF program and expanded definition of a Department of Labor program

4-3 Establish public-private partnerships to support successful STEM programs

4-4 Improve data provided by the Department of Education and the Bureau of Labor Statistics to STEM students, parents, and the greater community on STEM disciplines and the labor market

5. **Create a Presidential Council on STEM education with leadership from the academic and business communities to provide strategic leadership for transformative and sustainable change in STEM undergraduate education**.

Transformation and Opportunity: The Future of the U.S. Research Enterprise (November 2012)[146]

This PCAST report links the strength of the US economy and its connection to the American way of life to the capacity to innovate and use science and technology as innovation products, as its main source of growth. In the global economy, the importance of research and development is crucial, and is an investment in the future. While decades ago, corporate laboratories were carrying out much of the fundamental research of the time, now it is the universities that have become research hubs for national security, health, and environmental management.

[146] Report available here: http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_future_research_enterprise_20121130.pdf

The report spells out actions needed to preserve the US innovation advantage. With regards to the STEM workforce, the actions recommended follow in the footsteps of the 'Engage to Excel' report; namely, the adoption and use of empirically validated teaching methods and creating research opportunities for STEM undergraduates, as well as attracting and retaining the best world's students and researchers, adjusting for this purpose the visa system. In addition to this, the report mentions the need to solve career development and workforce issues related to early career scientists engaged in fields where there are few opportunities to advance further (Transformation and Opportunity, p.94-97).

Initiatives

Skills for America's Future

In October 2010, President Obama announced an initiative aimed at creating a national network of partnerships among employers, community colleges, industry associations, and other stakeholders. The initiative focuses on bridging the skills gap between the 3 million unfilled technical jobs while the unemployment rate is high. The resource is promoted to employers for fulfilling their staffing needs is the community college type institution, which is present almost everywhere, and attended by nearly 12 million students (44% of all undergraduates), among whom about half are employed. Community college type institutions generally have open admission, low tuition costs and offer remedial courses for students. So far, the program reports partnerships formed between more than 40 employers and over 200 community colleges across the US[147].

ARPA-ED

The 2010 report 'Prepare and Inspire' proposed the creation of a strategic education task force following the example of ARPA-E in energy. Initially the Obama administration requested in the 2012 fiscal year $90 million to fund the creation of ARPA-ED[148]. One year later, the funding source was changed to the 'Investing in Innovation' (i3) fund[149]. The ambitious project proposes to use the most recent technological breakthroughs to transform teaching and learning through education research and development. Possible outcomes are: digital tutors as effective as personal tutors, courses that improve the more students use them, and educational software as compelling as the best videogame [148].

Master Teachers Corps

In 2012, the provision of the 2010 report 'Prepare and Inspire' stipulating the creation of the Master Teachers Corps to recognize and reward the best STEM teachers was realized in the form of the Department of Education Teaching Incentive Fund (TIF), pending the approval of the full budget for the initial project by the Congress. From the $100 million fund put aside for STEM education, the first four school districts who applied and were selected have been funded[150].

---

147 Online at http://www.aspeninstitute.org/policy-work/economic-opportunities/skills-for-americas-future
148 Online at http://www.ed.gov/technology/arpa-ed
149 Online at http://news.sciencemag.org/scienceinsider/2012/02/obamas-budget-shuffles-stem.html
150 Awards are announced on a rolling basis at http://www2.ed.gov/programs/teacherincentive/apps2012stem/index.html

STEM Talent Expansion Program (STEP) – Graduate 10K+ Focus

The STEP program[151] added a new focus in 2012 with the Graduate 10K+ initiative to increase the annual number of engineering and computer science B.S. graduates by 10,000. The initiative is the result of a cooperative activity between the President's Jobs Council and the National Science Foundation (NSF). The funding is dedicated to projects aimed at increasing retention during the first two years in college, when students choose their major. Based on studies which showed that engineering and computer science majors are particularly susceptible to the correlation between retention within the first two years and graduation, the initiative is focused on these two majors.

Educate to Innovate

In 2009, President Obama initiated Educate to Innovate[152] (EtI). To date, the main part of EtI seems to be the development of public-private partnerships to foster interest and engagement in STEM, mostly in the form of out of school activities. One of the initiatives involved programming changes for a few science-related television programming. The iconic Sesame Street program agreed to incorporate a greater focus on STEM content on the show and in their curricula and they claim[153] noteworthy results for improving knowledge and interest. In a similar vein, Discovery Communications[154] agreed to provide a few hours of commercial-free STEM-related programming each afternoon on the *Science Channel* for middle school students. EtI also formalized National Lab Day and the annual White House Science Fair[155], in an effort to bring STEM to the national forefront for all students and for those top students capable of advanced research projects.

Possibly the most significant piece of EtI is *Change the Equation* (CTEq), a non-profit organization created to coordinate and expand efforts of corporations toward improving STEM achievement and persistence[156]. CTEq's members[157] include many of the largest science and technology-related companies in the US, including Google, Intel, Boeing, Microsoft, Exxon Mobil and others. While it seems that CTEq is just gathering steam, the idea of coordinating the efforts of industry toward improving STEM parallels what the COMPETES Act requested of federal agencies.

Common Core State Standards (CCSS)

Recent high-profile reports (e.g., PCAST, 2010) have called for a common, rigorous set of 'national' standards and thus there has been a significant push by policymakers for their creation. While not a federal effort, recent development of a common set of standards for K-12 in English Language Arts (ELA), mathematics, and more recently, science, has been a coordinated attempt across most states to create a 'common core'. Some of the arguments behind moving toward a common set of standards is that they

151 Description of the program is found online at http://www.nsf.gov/pubs/2012/nsf12108/nsf12108.jsp

152 Press Release: http://www.whitehouse.gov/the-press-office/president-obama-launches-educate-innovate-campaign-excellence-science-technology-en

153 Retrieved from: http://www.sesameworkshop.org/what-we-do/our-initiatives/stem.html

154 http://corporate.discovery.com/discovery-news/discovery-communications-to-launch-new-multimedia/

155 http://www.whitehouse.gov/blog/2012/02/07/president-obama-hosts-white-house-science-fair

156 http://changetheequation.org/about-change-equation

157 http://changetheequation.org/members

will 'create the need and opportunity for fair and valid assessments that measure what students have learned and benchmark U.S. performance against that of other countries.'[158] Some opponents disagree and argue that such standards will homogenize education and thus reduce creativity in American students[159]. Data from a national poll indicate that the public generally seems to believe that the common core will make the quality of education more consistent (75%), but only about half of those polled feel that they will improve the quality of education (50%) and make the US more competitive globally (53%)[160].

Thinking about producing a set of standards that are shared across states is not new. In both math and science, there have been multiple prior efforts, since the 1980s, by the National Council of Teachers of Mathematics (NCTM) in mathematics[161,162] and by AAAS[163,164] and the National Research Council (NRC)[165] to explicate the knowledge that we should expect mathematically- and scientifically-literate citizens to understand. The idea was for these documents to be used as guidance from which states could build their own specific, but similar standards. However, the authors of PCAST (2010) concluded that the resulting state standards were often extensive compendiums of accumulated knowledge. This translated into a focus by educators on factual recall rather than conceptual understanding and application.

One of the issues related to any form of standards creation is the production of instructional materials and assessments associated with the content and practices within the standards. In the past, publishers have avoided creating state-specific textbooks and instead opted to create large volumes that include the multiple variations of content that multiple states might cover. While it seems possible, as some argue, that a common set would make publishers compete for business and thus make content products with greater depth and enrichment, it will take a while before any conclusions can be made.

With these issues noted, it is not clear why designers and advocates of the new standards believe that outcomes will be any different this time around. One major difference, that may have an effect, is that the standards have a hierarchical structure such that there are a limited number of major concepts, each with its own set of sub-concepts, which are meant to help states and educators prioritize what is most important to focus on.

The most recent CCSS effort is being led by the National Governors Association and the Council of Chief State School Officers. The mission statement for these standards,

---

158 PCAST (2010) p. 43

159 Yong Zhao Interview from: http://blogs.edweek.org/edweek/bookmarks/2012/07/zhou_on_entrepreneurship_the_common_core_and_bacon.html

160 Bushaw, W. J., & Lopez, S. J. (2012). Public education in the United States: A nation divided. *Phi Delta Kappan, 94*(1), 8-25. Full text available here: http://www.pdkintl.org/poll/docs/2012-Gallup-poll-full-report.pdf

161 NCTM Commission on Standards for School Mathematics. (1989). *Curriculum and evaluation standards for school mathematics*. Reston, VA: NCTM.

162 Principles and Standards for School Mathematics (2000) http://www.nctm.org/standards/content.aspx?id=26798

163 Rutherford, F. J., & Ahlgren, A. (1989). *Science for all Americans*. New York: Oxford University Press. Available here: http://www.project2061.org/publications/sfaa/online/sfaatoc.htm

164 AAAS. (1993). Benchmarks for scientific literacy. New York: Oxford University Press. Available here: http://www.project2061.org/publications/bsl/online/index.php

165 NRC. (1996). *National Science Education Standards*. Washington, DC: The National Academies Press. Available here: http://www.nap.edu/openbook.php?record_id=4962

quoted below, is reminiscent of the rhetoric regarding global competitiveness discussed previously:

> The Common Core State Standards provide a consistent, clear understanding of what students are expected to learn, so teachers and parents know what they need to do to help them. The standards are designed to be robust and relevant to the real world, reflecting the knowledge and skills that our young people need for success in college and careers. With American students fully prepared for the future, our communities will be best positioned to compete successfully in the global economy.[166]

As is the process for most educational standards in the U.S., drafts of the standards were reviewed by multiple stakeholders and after revisions were made available for public comment. To date, 45 of 50 states have adopted the new Common Core standards and are in various stages of classroom implementation.

The mathematics standards[167] are set up to include mathematical practices as well as content for grades K-12. The practices[168] involve elements from both the NCTM and the NRC, including: a focus on problem solving, reasoning and proof, communication, representation, procedural fluency, conceptual understanding and productive dispositions toward mathematics.

The contents standards for mathematics are organized into 11 different domains for grades K-8, including: Counting & Cardinality (Grade K), Operations & Algebraic Thinking (K-5), Number & Operations in Base Ten (K-5), Number & Operations—Fractions (3-5), Measurement & Data (K-5), Geometry (K-8), Ratios & Proportional Relationships (6-7), The Number System (6-8), Expressions & Equations (6-8), Functions (8), Statistics & Probability (6-8). The standards for high school are separated out from these and include: Number & Quantity, Algebra, Functions, Modeling, Geometry, Statistics & Probability. There is no specific sequence given to the high school standards, but they identify concepts students should understand to be ready for college and career[169].

While science content was not an explicit part of the original standards, it was included within the ELA standards as a literacy component, especially for grades 6-12. In general, the focus of these standards is on understanding technical language and visualizations, explaining the steps of experimentation and the use of evidence in arguments.

In terms of an explicit set of science standards, the Next Generation Science Standards (NGSS) have been in development for a few years now. The first part of the development involved coming to a consensus about what science students should know across K-12[170]. Initially, the National Research Council convened panels of experts across the various science and engineering disciplines, as well as from science education and the learning sciences to outline all of the science information students

[166] Text quoted from: http://www.corestandards.org/
[167] National Governors Association Center for Best Practices, Council of Chief State School Officers. (2010). Common Core State Standards in Mathematics. Washington, DC: National Governors Association Center for Best Practices, Council of Chief State School Officers.
[168] Details from: http://www.corestandards.org/Math/Practice
[169] http://www.corestandards.org/Math/Content/note-on-courses-transitions/courses-transitions
[170] Information retrieved from: http://www.nextgenscience.org/development-overview

should comprehend. A draft of this was made available for public release in 2010, and based on public comment, a final version of the document, the *Framework for K-12 Science Education*[171], was released in mid-2011.

The Framework set the stage for development of the actual standards. Achieve Inc.[172], a non-profit and non-partisan organization focused on improving achievement and assessment, is leading the development of the standards and coordinating efforts with the National Science Teachers Association, AAAS and NRC. Based on the Framework, standards are currently being written to address three dimensions: Science and Engineering Practices, Crosscutting Concepts and Core Ideas. These dimensions will be discussed in more detail below. The second draft of the standards was released in early January 2013 and the public were given 3 weeks to make comment before revisions will be made and a final set of standards released in March 2013. A full review of these draft standards is not warranted here, but key changes from prior efforts to create a *de facto* set of national standards are discussed.

Probably the most significant change from prior standards documents is the format and delineation of the standards. As mentioned, the standards are separated into three dimensions including: Science and Engineering Practices, Crosscutting Concepts and Disciplinary Core Ideas.

The Science and Engineering Practices are expectations for how students should experience science. Many perceive this to be inquiry learning in a new form, but the practices are presented in a different format in the hope that educators will find it easier to incorporate the practices into their instruction. The Science and Engineering Practices[173] include:

- Asking questions (for science) and defining problems (for engineering)
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics and computational thinking
- Constructing explanations (for science) and designing solutions (for engineering)
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information.

The incorporation of explicit practices related to engineering is a significant change from prior sets of standards. One important note – the NGSS make clear that it is not enough for educators to merely discuss these Practices as things scientists and engineers do, but to actively engage students in these Practices so they can learn science by doing science.

---

171 NRC. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, DC: The National Academies Press. Full text available here: http://www.nap.edu/catalog.php?record_id=13165

172 http://www.achieve.org/

173 Information available here: http://www.nextgenscience.org/sites/ngss/files/Appendix%20F_Science%20%20Engineering%20Practice%20-%20FINAL.pdf

In regards to the content standards, they have been revised in NGSS and now exist as performance expectations rather than facts or concepts students should know[174]. The expectations come in the form of Disciplinary Core Ideas (DCIs) and Crosscutting Concepts (CCCs). The DCIs involve the aspects critical to understanding the major domains of physical science, life science, earth and space science, and engineering (including technology and applications). The CCCs are those overarching ideas that bridge multiple science domains. They include: Patterns, similarity and diversity; Cause and effect; Scale, proportion and quantity; Systems and system models; Energy and matter; Structure and function; and Stability and change[175]. The writers of the standards make very clear that they are not meant to be a curriculum, but they are the expectations for what a student should be expected to know and be able to do at the end of courses or grade bands (i.e., K-2). While the draft NGSS appeared to be quite complex in format, one major improvement over previous standards was the inclusion of cross-curricular information to simplify integration with mathematics or language arts. As with many other reforms, we will have to wait a while to see if when and how these are implemented.

Evaluation of the policies

In attempting to answer the question as to whether the policies described herein have been effective, the first step is to evaluate the extent to which recommendations included in policy reports have been implemented. From this point of view, while there are functional elements already in place (STEP-Graduate 10K+, Skills for America's Future, Educate to Innovate), others are either in the process of being made (e.g., Common Core and NGSS), or were created but are not at full capacity as planned (Master Teachers Corps, ARPA-ED), and others are yet to be developed (STEM strategy metrics). Reasons for this state of affairs range from existing degrees of political determination to implement changes to the time needed for the structure of policy to coalesce around interested stakeholders. The current situation can be described by stating that many policy reports have been released, but few recommendations have manifested as policies, likely as an effect of partisan politicking in approving budgets. Also, in some cases the delays from the initial estimated time to implementation are due to unforeseen external, uncontrollable factors; while in other cases it is normal for implemented projects to take longer to run their course and then results to be reported.

Among the elements of the STEM strategy that have yet to be finalized are metrics - as proposed by the *Engage to Excel* report - to be elaborated by National Academies. One of the main features of these metrics to be used to measure the progress in the implementation of the measures is that they should solve the misalignment issue between assessment as prescribed by No Child Left Behind and STEM learning goals.

Another element with the role of benchmark is a set of national standards, as the ones for mathematics, to be elaborated by Achieve Inc., and the NGSS for science education, currently in final revisions. The standards are meant to address the current problems arising from uneven state standards and subsequent variability in teacher quality.

---

174 More information available here: http://www.nextgenscience.org/sites/ngss/files/Appendix%20A%20-%20Conceptual%20Shifts%20in%20the%20Next%20Generation%20Science%20Standards%20-%20FINAL.pdf

175 http://www.nextgenscience.org/three-dimensions

The Advanced Research Projects Agency for Education (ARPA-ED) task force in STEM education, first announced in the 'Prepare and Inspire' 2010 report, was included in President Obama's budget requests. As mentioned before, funding eventually was allocated from the 'Investing in Innovation' fund, not yet as initially planned.

Limitations mentioned in the CoSTEM report

The February 2012 the CoSTEM Report identified several external factors which are outside of the Federal agencies' control, which can significantly affect the achievement of strategic goals[176]:

- The Federal government's lack of authority to create a national STEM education curriculum or set of standards;
- Budget fluctuations and changes in views of agencies' roles are affecting the long-term planning;
- Certain agencies cannot by law target underrepresented groups;
- Coordination between agencies is difficult with limited funding;
- Data confidentiality rules limit evaluation strategies.

Additionally, some agencies either do not have STEM education expertise, or their mission does not have it as a focus, or the investments it does in STEM education are distinct and decoupled. At the same time, the procedures for solicitation, review, and awarding grants are inconsistent, and inter-agency coordination for the purpose of joint programs are time-consuming and costly.

176 CoSTEM Report, February 2012, p. 12.

Nationwide vs. worldwide STEM talent

Another policy concern is determined by the apparent dilemma between attracting foreign STEM talent and nurturing homegrown STEM talent. While the instruments for achieving each are as different as immigration policies are to educational policies, the resulting qualified STEM workforce is a combination of the two sources, and, while there might be a certain level of increased competitiveness on the STEM job market, in practice the result is that of a complementarity. Survey data seems to show that, even if they study in the same field, immigrant and US-born STEM learners have preferences for different subfields, as is the case of condensed matter physics and astronomy/astrophysics[177,178].

Hurdles in reforming STEM education

Recent gains in cognitive sciences and discipline-based education research (DBER)[179], translated to classroom learning experiences are not yet widely known by STEM teachers. This slow diffusion of research-based teaching methods has several causes. One is the way most current teachers were trained and most students are currently taught[180], by reinforcing of ineffective existing teaching approaches. One approach of special concern is the traditional tendency in gateway STEM courses of teaching for the prepared students, instead of adapting the material for the students' sociocultural and experiential backgrounds. At the same time, there is a certain difficulty for teachers to learn new skills in intermittent, short duration activities, such as the summer courses aimed at improving their teaching skills. Last, but not least, there is a certain existing tension between university research and teaching in the academic culture[181]; sometimes research is favored at the cost of quality teaching, and the students are the first to face the effects of courses which do not motivate them toward studying STEM. Additionally, as the DBER paradigm is gaining ground, traditional STEM scholars are reluctant to accept the results of educational research in teaching their discipline, attitude which sometimes can degenerate in bitter intergenerational conflicts[182] within academia.

Controversial scientific issues

The real or apparent lack of consensus on certain scientific issues, as sometimes reflected in the mass media, is affecting the federal support of research and training of future STEM workers in certain subfields.

Climate change: Despite unequivocal evidence on global climate system warming[183], mass media presented the issue as still unsettled[184]. This coverage also influences the public opinion on high-risk, high-payoff federal investment initiatives in green energy.

---

177 American Institute of Physics, *Focus on Physics Graduate Degrees,* July 2011, online at http://www.aip.org/statistics/trends/reports/physgrad2008.pdf

178 Florin Lung, Geoff Potvin, Gerhard Sonnert, and Philip Sadler, *Majoring in Physics or Astronomy? Answer is in Students' Past*, Presentation at the 2012 AAPT Meeting, August 2012, Philadelphia PA

179 See Appendix B for a presentation of DBER

180 http://news.sciencemag.org/scienceinsider/2012/09/wieman-tells-senators-what-doesn.html

181 http://news.sciencemag.org/scienceinsider/2012/02/report-outlines-steps-to-more-us.html

182 A recent example of the incidents typical for 'math wars' is presented at http://www.insidehighered.com/news/2012/10/15/stanford-professor-goes-public-attacks-over-her-math-education-research

183 http://www.ametsoc.org/policy/2012climatechange.html

184 http://www.sciencedirect.com/science/article/pii/S0959378010000300

The issue often became politicized, as was the case with thin-film solar cells manufacturer Solyndra's bankruptcy[185], or even the legislative initiatives aiming at higher energy efficiency in the households[186].

Intelligent design: The creationist theory advanced by Discovery Institute[187] is viewed by some as an alternative to the mainstream life sciences, which are heavily based on the principle of evolution of species. Public opinion surveys show that the American public favors such alternative approaches[188]. Scientists generally consider such views as threatening science education[189], yet there are a number of private higher education institutions where biosciences students prepare for technician careers without having in the curriculum courses on evolution.

Stem cell research: Based on ethical concerns, President George W. Bush vetoed the *Stem Cell Research Enhancement Act* twice, in 2006 and 2007[190]. As a consequence, while not banned at that time, stem cell research had limited support. After being elected to the White House, President Obama overturned in 2009 the policies limiting NIH funding of stem cell research[191].

Negative views on science: The new STEM Sputnik moment announced by President Obama's 2011 State of the Union Address[192] was viewed by some commentators as being in opposition to the support for the free market and small businesses[193]. More generally, legislators not always follow the evidence when weighing on scientific issues[194].

Recommendations for the Australian decision makers

From the examination of recent trends in American STEM education, we can extract several recommendations that we hope are of use for Australian policymakers:

. Given the complexity of the challenge and its importance for the national economy, measures to be taken should reflect a concerted national effort and cooperation beyond party differences, to provide the focus and continuous funding to make possible the continuity needed for long-term plans to come to fruition.

. Given the multitude of approaches needed and the large number of interested parties, a structural, strategic approach is recommended, including the creation of a central task force on STEM education, which should have partners at the state and local levels, where the strategy can be adjusted to the specific local context.

. Regarding the cost of implementation for such programs, while substantial, it should be seen as an investment which will pay off in the future. Ideally its implementation

185 http://abcnews.go.com/Blotter/solyndra-loan-now-treasury-launching-investigation/story?id=14521917
186 http://www.nytimes.com/roomfordebate/2011/03/17/the-politicized-light-bulb
187 http://www.discovery.org/
188 http://www.gallup.com/poll/21814/evolution-creationism-intelligent-design.aspx
189 http://apnews.excite.com/article/20120924/DA1G1IKG2.html
190 http://abcnews.go.com/Politics/Health/story?id=2788052&page=1
191 http://www.cnn.com/2009/POLITICS/03/09/obama.stem.cells/index.html
192 http://www.whitehouse.gov/the-press-office/2011/01/25/remarks-president-state-union-address
193 http://www.cbsnews.com/8301-503544_162-20029942-503544.html?tag=contentMain;contentBody
194 http://www.wired.com/wiredscience/2012/08/house-committee-science/

should start early, while taking advantage of the economic growth, to create the conditions for future economic growth.

. Since most of the demand is predicted to be for holders of STEM certificates and Associate degrees, a good deal of focus should be on these educational levels. This approach also has the advantage of being less cost-intensive than full Bachelor's or graduate degree programs, although the sheer number of enrolments in certificate and Associate programs could present financial challenges.

. Encourage growth of existing networks of DBER scholars in science education departments who are following the disciplinary developments in the U.S. and Europe, and create the premises for the science departments to start developing their own DBER programs and hiring new faculty who will complete research in physics education, chemistry education, biology education, mathematics education, and engineering education.

. Take advantage of the qualified immigrant STEM workforce by providing them with legal pathways to gaining legal residence, while keeping a judicious balance between the STEM workforce trained in Australia (Australian-born and assimilates of them) and immigrants.

. Since at the moment there we are not aware of equivalents of National Science Foundation's calls for proposals from the Australian Research Council, steps should be taken towards either instituting some disciplinary committees in STEM education, which would be tasked with the elaboration of such calls for grant proposals for disciplinary STEM education programs, or, if this is not desired, elaborate at the governmental level guidelines which would reflect national research priorities and coordinate efforts across agencies.

Appendix A

Federal STEM Education Investment

In December 2011, CoSTEM released the Federal STEM Education Portfolio report[195], which was to accompany the CoSTEM Report presenting the strategy for implementing America Competes, report released later in February 2012. The Federal STEM Education Portfolio report provided a detailed inventory of Federal agencies' spending on STEM education.

Among the major findings of the report is the total $3.4 billion dollars spent by Federal agencies on STEM education investments, broken down on the needs of the workforce catered for by specific agencies (28% from the total), as well as broader STEM education, making up the rest, dominated by National Science Foundation and Department of Education investments, as seen in Figure A.1. In addition, the investments which primarily address groups underrepresented in STEM add up to $1.1 billion, while nearly one in two other investments targets underrepresented groups in STEM as a secondary goal. As to the specific goal of improving teacher effectiveness, a total budget of $312 million in funds goes to such investments, most of it being for teacher professional development. Counting both primary and secondary objectives of investments toward teaching effectiveness, they make up almost half of the investments in STEM education.

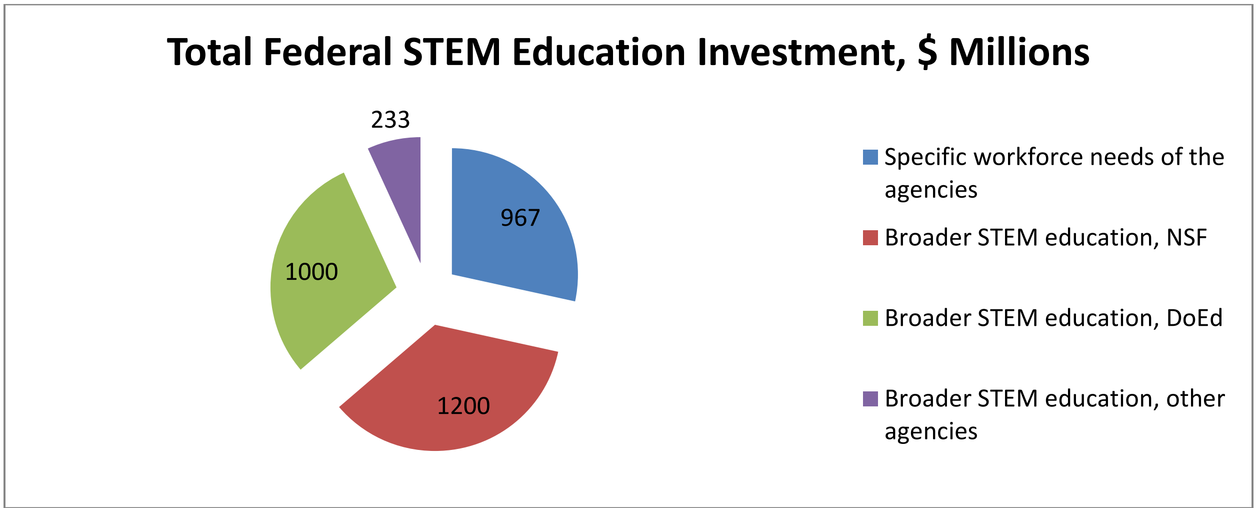


Figure A.1. STEM Education Investment [Based on data from Federal STEM Education Portfolio, 2011]

A more thorough picture on Federal STEM education investment emerges by examining Table A.1, which details both broader STEM education and agency-specific STEM education for each Federal agency. The total investment, broken down by primary objective, is also shown in Table A.2. The three largest STEM agencies in terms of STEM education investment, namely: Department of Education, Department of Health and Human Services, and National Science Foundation, are shown in more detail in Figures A.2-4.

195 Online at http://www.whitehouse.gov/blog/2011/12/09/ostp-releases-federal-stem-education-portfolio

Another finding of the report is that while there is a moderate degree of overlap between investments made by different agencies, having some of the same objectives, audiences, products or services, and STEM fields, there were no duplicates found.

	Broader STEM		Agency Mission Workforce	
	Investment $ (in millions)	# of Invest.	Investment $ (in millions)	# of Invest.
USDA	$ 31.38	3	$ 61.07	14
DOC	$ 51.54	15	$ 21.25	4
DOD	$ 46.44	7	$ 97.71	9
DOEd	$ 1,001.18	15		
DOE	$ 10.12	6	$ 50.67	19
EPA	$ 7.60	3	$ 10.38	5
HHS	$ 35.45	7	$541.47	29
DHS			$ 6.81	4
DOI			$ 0.57	1
NASA	$ 132.38	43	$ 44.79	19
NSF	$ 1,154.41	39	$ 14.87	1
NRC	$ 2.84	1	$ 13.50	3
DOT			$ 103.87	5
Total	**$ 2,473.33**	**139**	**$966.96**	**113**

Table A.1. STEM Education Focus by Federal Agency [Taken from Federal STEM Education Portfolio, 2011]

	Broader STEM		Agency Mission Workforce		Total	
	Investment $ (in millions)	# of Invest.	Investment $ (in millions)	# of Invest.	Investment $ (in millions)	# of Invest.
Learning	$ 243.08	32	$ 53.32	16	$ 296.40	48
Engagement	$ 157.16	36	$4.35	6	$ 161.50	42
Pre- and In-Service Educators	$ 311.71	24	$0	0	$ 311.71	24
Post-Secondary STEM Degrees	$ 678.92	18	$488.65	53	$ 1,167.56	71
STEM Careers	$ 480.25	5	$372.08	30	$ 852.33	35
Institutional Capacity	$ 82.87	12	$48.57	8	$ 137.43	20
Education Research and Development	$ 519.35	12	$0	0	$ 519.35	12

Table A.2. STEM Funding and Number of Investments by Primary Objective [Taken from Federal STEM Education Portfolio, 2011]

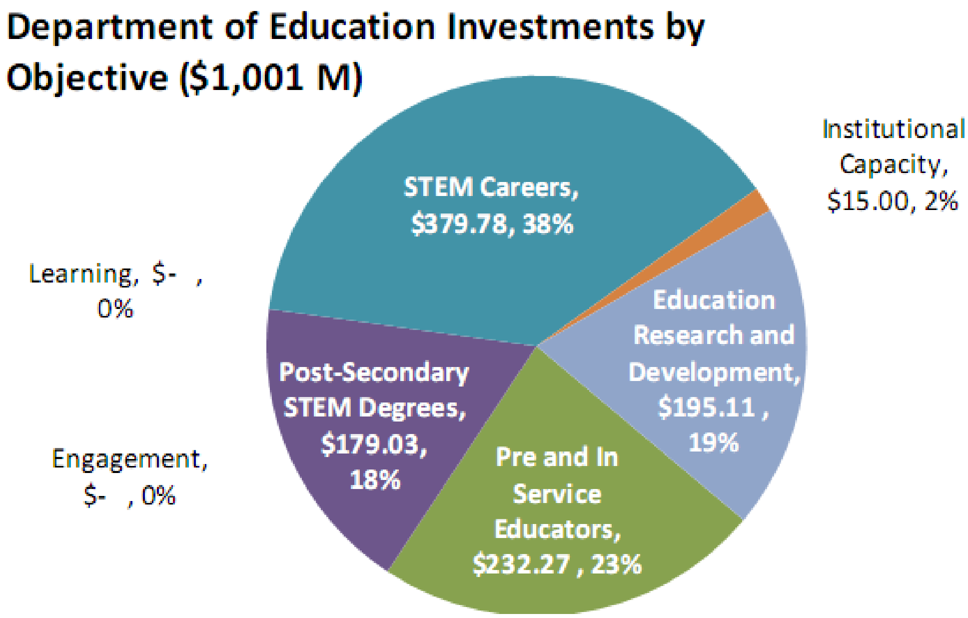


Figure A.2. Department of Education's STEM Education Investment [Taken from Federal STEM Education Portfolio, 2011]

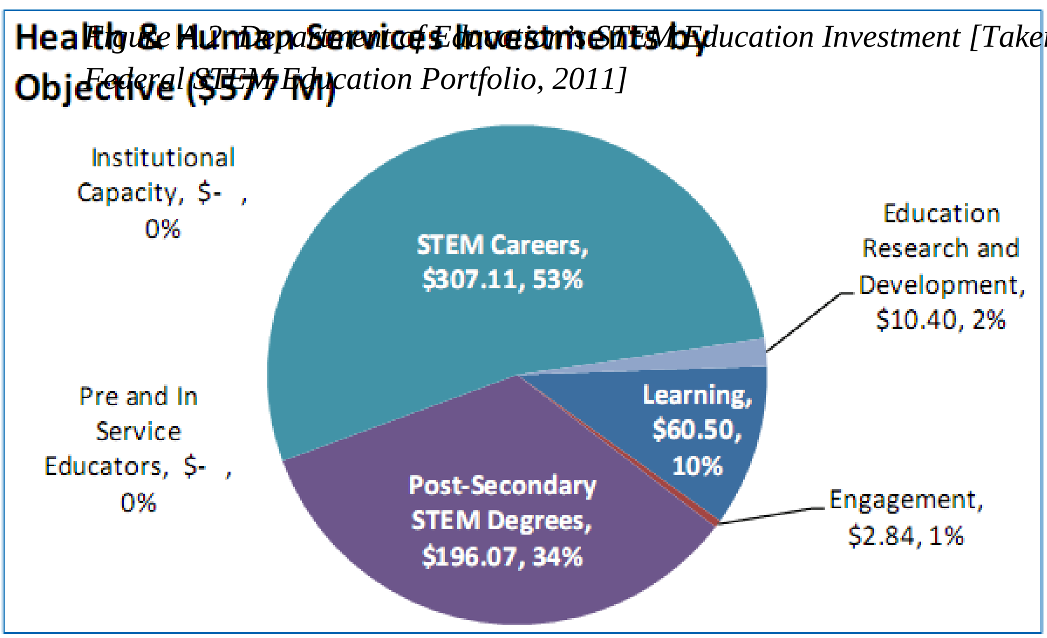


Figure A.3. H&HS Department's STEM Education Investment [Taken from Federal STEM Education Portfolio, 2011]

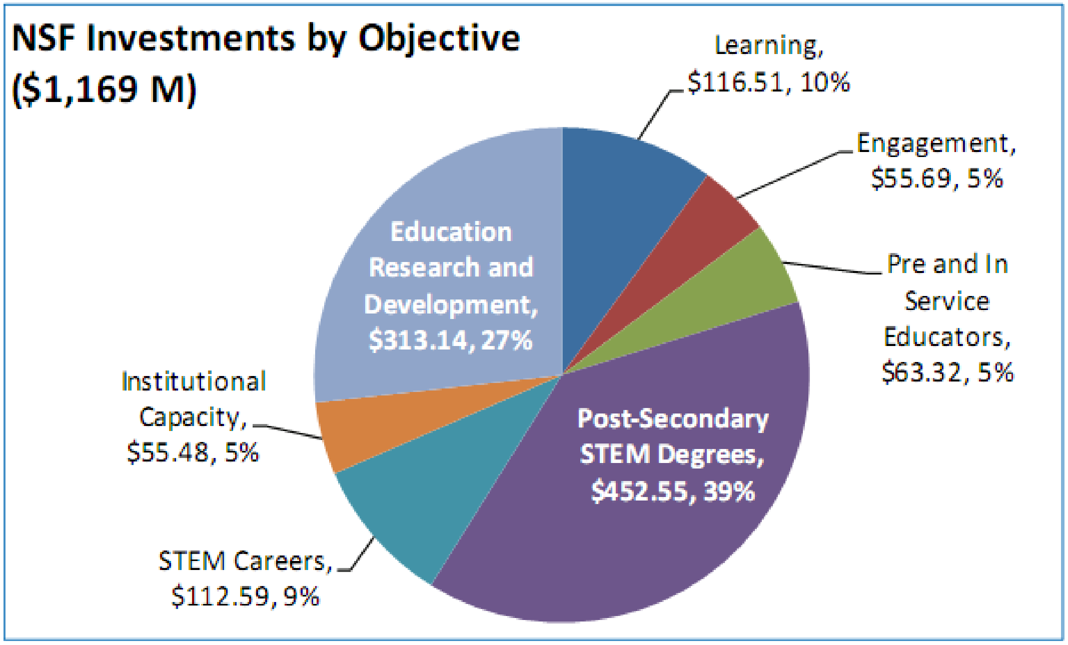


Figure A.4. NSF's STEM Education Investment [Taken from Federal STEM Education Portfolio, 2011]

National Research Foundation STEM education funding trends

The National Science Foundation (NSF) is the only federal agency supporting education across all science and engineering fields. It also has the most STEM education funding and the largest number of programs. Mostly, the NSF funds go toward STEM research and education. However, these missions are not always distinct, since on the one hand education prepares future STEM workers and researchers, and on the other hand students and junior researchers are involved in research activities, which constitute for them learning experiences. For this reason, depending on the criteria assumed, the proportions of different categories of funded activities can differ.

The three main activities in NSF's budget are: research and development (R&D), education and training (E&T), and non-investment activities (NIA), primarily of an administrative nature. The breakdown of total NSF funding on these categories, between 2003 and 2012 (data for the fiscal year 2012 were estimates), using a different formula than the one used in Figure A.4, is shown in Figure A.5[196].

[196] Heather B. Gonzalez, *An Analysis of STEM Education Funding at the NSF: Trends and Policy Discussion*, Congressional Research Service R42470, online at www.fas.org/sgp/crs/misc/**R42470**.pdf

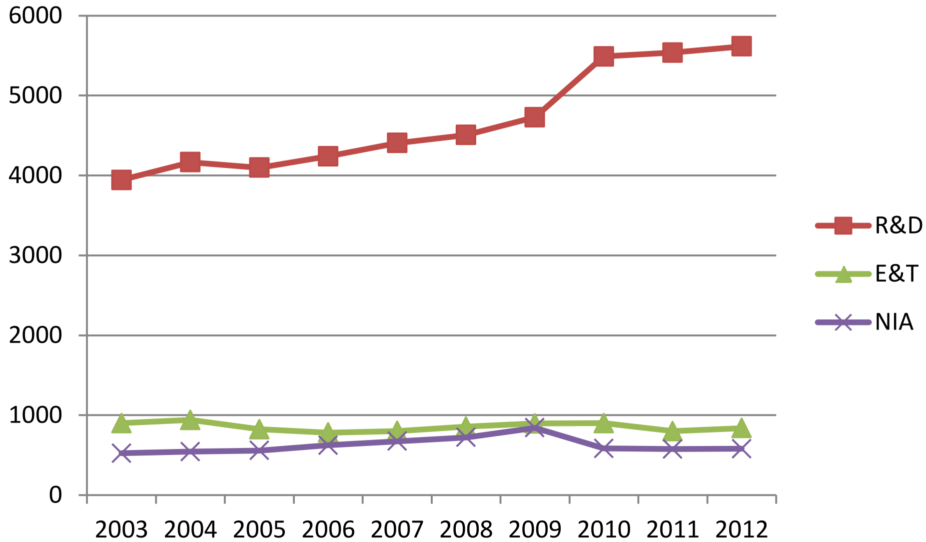


Figure A.5. The categories of funding activities by NSF between 2003 and 2012 in Million US $ [Data taken from CRS 7-5700]

As can be seen in Figure A.5, while the total NSF funding has increased starting in 2009, this is mostly due to the funding of R&D activities, since E&T activities have remained historically at about the same level. This report was released a few days after the CoSTEM's STEM Education Portfolio report, and while it uses a different data aggregation method, making it less usable in conjunction with the CoSTEM Portfolio report, it has the advantage of providing a glimpse into the historical trends in STEM R&D and E&T funding.

Appendix B

Research in STEM Education (Discipline-Based Education Research, DBER)

In the past few decades, academic research fields generically named DBER have been constituted in relation to learning sciences such as *physics, chemistry engineering, biology, geosciences, and astronomy*. All these disciplines are distinct, reflecting differences between their parent disciplines, but study similar problems, using similar theories, and use similar methods. As defined by National Research Council's DBER Committee in 2012[197], the goals of DBER are:

- To understand how people learn the concepts, practices, and ways of thinking in science and engineering;
- To understand the nature and development of expertise in a discipline;
- To help identify and measure appropriate learning objectives and instructional approaches that advance students toward these objectives;
- To contribute to the knowledge base in a way that can guide the translation of DBER findings to classroom practice; and
- To identify approaches to make science and engineering more inclusive.

The practical goal of DBER to improve science and engineering education for all students has to be achieved by grounding it in expert knowledge of the discipline and the specific challenges in learning, teaching, and professional thinking within each discipline. Thus, besides knowledge within the science and engineering disciplines, DBER, as an interdisciplinary field of study, relies on:

- The nature of human thinking and learning as they relate to the discipline of interest;
- Factors affecting student motivation to initially engage and later persist in the learning needed to understand the discipline and apply its findings;
- Research methods appropriate for investigating human thinking, motivation, and learning.

A useful framework for understanding the approaches of DBER is constituted by Pasteur's quadrant from Figure B.1, in which pure basic research, pure applied research, and also use-inspired basic research, which comprises an important number of DBER studies. The set of backgrounds of DBER scholars influence their approach, some of them holding positions in science departments, others in department of education, depending on their main expertise. Also, the tendency is to work in collaboration with scholars having complementary fields of expertise than their own.

[197] http://www.nap.edu/catalog.php?record_id=13362

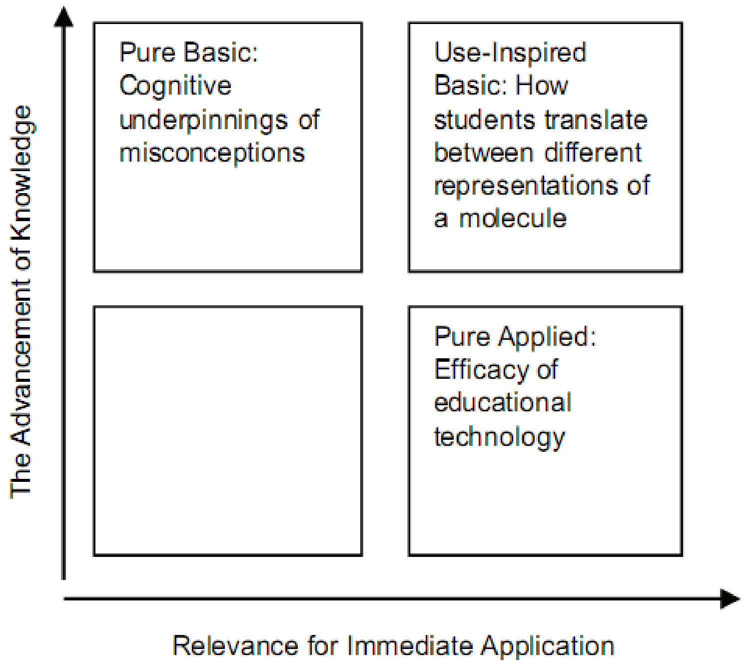


Figure B.1. Pasteur's quadrant showing basic and applied DBER [National Research Council, 2012]

Although it has significant overlaps with other fields studying teaching and learning, DBER is a distinct field from these:

- *Scholarship of teaching and learning* (SoTL) has developed in parallel with DBER. SoTL emphasizes developing reflective practice and using classroom-based evidence, its findings that, unlike DBER, are published in generalist journals, strive to improve teaching effectiveness more broadly, student learning outcomes, and the transformation of academic cultures and communities.
- *Educational psychology research* informs DBER with respect to general principles of age-related learning.
- *Cognitive sciences research* in artificial intelligence, linguistics, anthropology, psychology, neuroscience, philosophy, and education, provide DBER with understanding of the nature of human mind and other intelligent systems.
- *Educational evaluation* provides measurement of effectiveness for instructional strategies, course structures, programs of study, including the ones resulting from discipline-based educational research.

Disciplinary branches of DBER

Historically, the first elements of DBER can be traced back to the concerns about the quality of teaching and learning science at the time of expansion of colleges and universities in the US, in the late 1800s and early 1900s. However, at that time judges for quality were disciplinary experts according to the disciplinary internal logic. Another important moment was the wake of Sputnik satellites launch, when the U.S. began an ambitious program to regain the top spot in science, and the NSF funded projects involving development of science curricula. The third historical phase is between 1970s and 1990s, when individual DBER fields gained recognition within their own science disciplines, as seen by the establishment of professional societies, dedicated journals, and graduate programs and postdoctoral fellowships. On the other hand, currently the most studied population in DBER is the one representing undergraduate students, as well as students taking high school science courses. Gradually, graduate education and learning in sciences and engineering, as well as STEM education and learning at earlier ages are becoming more and more studied. Perhaps one of the most notable results is Lawson's scientific reasoning developmental model[198], an extension of a prior model developed by the Swiss psychologist Jean Piaget[199]. One of the most important DBER journals is the Journal of Research in Science Teaching (JRST)[200], reflecting the scholarly works of the members of National Association of Research in Science Teaching (NARST).

Physics education research (PER)[201]: in the 1960s, the efforts of several PER groups resulted in undergraduate and K-12 curricular programs[202][203]. Later, in the 1970s, the PER scholars lost their audience, until the 1990s, when PER PhD programs began to be established. This was followed by a dedicated journal in 2005, *Physical Review Special Topics – Physics Education Research*[204]. A growing PER community in the U.S. gathers annually at the Physics Education Research Conference, organized in conjunction with the American Association of Physics Teachers annual meeting. Among the results of this newer wave in PER are a multitude of curricular innovations and instruments, presented on the PER Users' Guide[205] web page. Also, conceptual inventories and surveys were elaborated for specific undergraduate, graduate, and high school physics courses. These inventories aimed at measuring the conceptual understanding of the phenomena studied in the course, and evaluating the students' gains during the instructional unit, usually a semester.

Astronomy Education Research (AER) mirrored the emergence of PER, but with a delay of about two decades. The funding scheme is similar, and although AER papers are still published in PER journals, there is an AER journal, the *Astronomy Education Review*, where studies on the teaching and learning of astronomy are published.

Separately, *Chemistry Education Research* (CER) and *Biology Education Research* (BER) groups are constituted around *American Chemical Society* with the *Journal of Chemical Education*, and *Chemistry Education Research and Practice*; and *National Associations of Biology Teachers* with peer-reviewed journals such as *Advances in Physiology Education, and CBE (Cell Biology Education)-Life Sciences Education*, respectively. Concept inventories and attitude surveys initially elaborated by PER scholars were also adapted for chemistry or biology.

---

198 A. E. Lawson, *The development and validation of a classroom test of formal reasoning,* Journal of Research in Science Teaching, 15(1), 11-24, (1978)

199 B. Inhelder, and J. Piaget. The Growth of Logical Thinking from Childhood to Adolescence. Basic Books, 1959

200 Available online at http://onlinelibrary.wiley.com/journal/10.1002/%28ISSN%291098-2736

201 Jennifer Docktor and Jose P. Mestre, *A Synthesis of Discipline-Based Education Research in Physics* (2011), online at http://www7.nationalacademies.org/bose/DBER_Docktor_October_Paper.pdf

202 Robert G. Fuller et al, *College Teaching and the Development of Reasoning*, Information Age Publishing, 2009

203 Robert G. Fuller et al, A Love of Discovery: Science Education – The Second Career of Robert Karplus (Innovations in Science Education and Technology), Springer, 2002

204 Online at http://prst-per.aps.org/

205 http://perusersguide.org/

Engineering Education Research (EER) is singular among the DBER disciplines in that its development was strongly influenced by the Accreditation Board for Engineering and Technology (ABET) via outcomes-based ABET engineering criteria, which specify a range of student learning outcomes, including specific knowledge, skills, and more general habits of mind and professional conduct. In the 2000s, a taxonomy of EER was elaborated around five priority areas (engineering epistemologies, engineering learning mechanisms, engineering learning systems, engineering diversity and inclusiveness, and engineering assessment [197, p. 25]. Initially built around the National Academy of Engineering, the EER community of scholars now has a strong presence in the *American Society for Engineering Education*. As for journals, besides the EER-exclusive *Journal of Engineering Education*, several other engineering journals publish EER papers.