# STEM Performance and Supply: Assessing the Evidence for Education Policy

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## Abstract

*The relationship between education policy and workforce policy has long been uneasy. It is widely believed in many quarters of American society that the U.S. education system is in decline and, what's more, that it bears significant responsibility for a wide range of social ills, including stagnant wages, increasing inequality, high unemployment, and overall economic lethargy. However, as analyzed in this paper, the preponderance of evidence suggests that the U.S. education system has produced ample supplies of students to respond to STEM labor market demand. The "pipeline" of STEM-potential students is similarly strong and expanding.*

The relationship between education policy and workforce policy has long been uneasy. It is widely believed in many quarters of American society that the U.S. education system is in decline and, what's more, that it bears significant responsibility for a wide range of social ills, including stagnant wages, increasing inequality, high unemployment, moral deterioration, and overall economic lethargy. Common are sweeping condemnations of U.S. education such as this one: "[A]fter World War II the United States appeared to reign supreme… As the years went by, one by one, country after country caught up to and then surpassed us in several industries and more or less across the board in precollege education. And still we slept" (Tucker 2011).

That these problems largely result from failings of the education system appears to have an intuitive appeal that, along with unexamined repetition by journalists, the public, industry leaders, researchers, and policy makers from across the political spectrum, has fostered widespread acceptance of these claims. These claims of education failure have become so prevalent, in fact, that many cite them without much empirical assessment of whether they are true or applicable to the problem being examined (see Teitelbaum 2014; Lowell and Salzman 2007). As a result, many in the education community now obligingly accept that they have a duty to drive national prosperity and innovation, and to reduce inequality, among many other goals, by producing enough students with the skills that employers need, ranging from basic literacy to the advanced expertise of the PhD. Any failure to meet these demands brings the education community a torrent of blame, as seen most prominently in persistent criticism for the supposed shortage of workers for the nation's STEM (science, technology, engineering, mathematics) workforce, a group considered crucial to technological innovation and scientific progress and thus to economic growth.

After decades of educational failure claims—which seem to persist unabated whether the economy is declining or ascending, whether technology is "maturing" or undergoing transformative innovation—a close empirical assessment seems warranted. How do we assess the education system's responsibility for economic and social progress if its failure is a constant, regardless of the state of the economy and society? What are the educational outcomes that can be considered meaningful indicators of school performance? The status of education in the economy's core technology and science sectors clearly needs a more detailed examination. This paper examines how adequately the education system performs in producing STEM workers to fulfill the needs of society, industry, government, and other employers. The paper also considers the nature of the persistent "shortage" narrative that pervades nearly any discussion of STEM needs in the United States and has done so for decades.[1]

An analysis of the particular case of STEM worker shortage claims is important for several reasons. First, this group of workers is widely cited as crucial to the economy because it drives economic growth through innovation. Second, it is an occupational group that should be providing good income and employment opportunities. Third, as the most difficult labor force segment to "produce," it requires highly technical skills, training, and abilities, and thus intensive, costly, and lengthy education.

The STEM shortage narratives rest on three key assertions: (1) there are not enough students with the requisite skills and education in the K-12 pipeline, (2) the educational performance of U.S. students is in decline and thus insufficient to supply STEM industries at levels comparable to those in other countries, and (3) critical STEM industries suffer from inadequate supply of qualified graduates. In this paper, we provide an empirical assessment of each of those points. First, we consider the numbers of STEM-potential students in the U.S. secondary education system that are needed to produce an adequate supply for the STEM industries. Next, we review the educational performance metrics of U.S. students over time and in comparison to other dominant global economies. We also discuss the numbers of STEM graduates produced. We conclude with an assessment of the evidence on STEM education for education policy.

## How Many Do We Need?

The first metric to establish is the number of STEM workers needed—a task more complicated than it first appears because there is no accepted definition of the fields included in the "STEM" classification. For the purposes of this analysis, to assess the capacity of the education system to produce highly educated STEM graduates, we limit the population to people with at least a bachelor's degree and computer science, and mathematics. No recognized bachelor's-level degree (hereafter abbreviated as "BA," denoting both Bachelor of Arts and Bachelor of Science (BS) degrees) exists for technology ("T"), except for engineering and manufacturing technology, both of which are already included under engineering ("E"). For consistency with nearly all other analyses, we exclude health fields. Although nearly all professional engineers have at least a bachelor's degree (a requirement to be licensed as a Professional Engineer, or PE), there is a substantial share of workers who self-report "engineer" as their occupational title although they have less than a bachelor's degree (see also Kuehn and Salzman 2018). The analysis here focuses primarily on the education supply and demand for workers with degrees at or above a bachelor's level. The education composition of STEM workforces by selected fields is shown in Fig. 1.

The U.S. labor market demand for STEM BA graduates consists of new entry-level openings and openings created by incumbent workers leaving a STEM job to retire or move to a different field. Firms hire for those positions as well as to fill openings created by workers changing employers and firms laying off or dismissing incumbent workers and replacing them with new hires. Because not all graduates are qualified or suitable for the

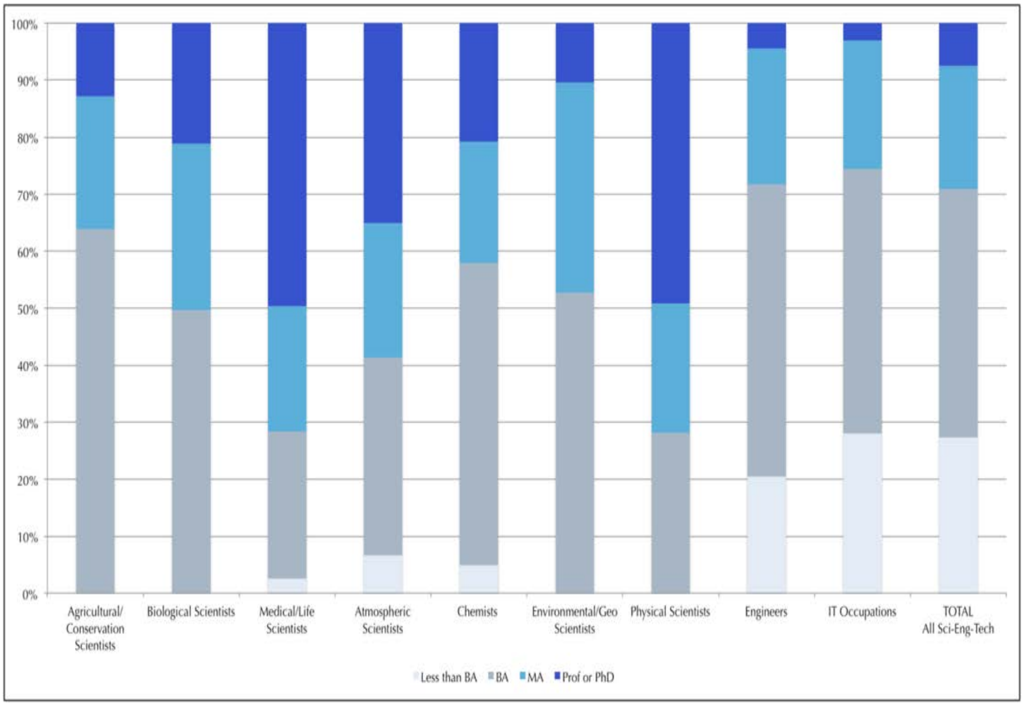
[1] Although it is now fashionable to look at the first decades of the post-World War II period as the golden age of U.S. education—in which education was once winning the race against increasing skill demands of technology—this nostalgia is belied by the actual accounts of the time that decried national education crises and shortages, albeit ideologically rather than empirically driven arguments that, as we will show, are repeated in today's narratives (Ravitch 1983, 2014; Rothstein 1998).

available jobs, and because some will, for a variety of reasons, decide to pursue other options, the number of graduates should ideally be larger than the number of openings. There is, however, no known method for calculating the optimal number of graduates needed to yield the desired number of employed STEM workers. We can determine the historical rate of employment yield, but this provides only a guide to prospectively estimating the number of graduates who will be hired into, or will take STEM jobs after graduation.

The demand in STEM occupations for BA graduates in a nationally representative college cohort—that is, the number hired into a STEM job within the four years after graduation, but not counting those who go on to graduate school or are not in the labor force—is about 60% of the 250,000 to 336,000 students who have graduated with STEM BA degrees each year in the past decade. (Figure 2 shows STEM occupation entry of those employed one year and four years after graduation for 1993 and 2008 BA cohorts[2]; Table 1 shows the number of STEM graduates since 1970; BA-level STEM include the natural or physical sciences, engineering,

**Fig. 1** *STEM occupations by educational attainment, 2016*

*(Source: BLS Employment* Projections http://www.bls.gov/emp/ep_table_111.htm)




majors who are hired into STEM occupations number about 183,000 in each of the recent graduating cohorts.) Even in the high-demand areas of computer science and engineering, the number who graduate each year exceeds the number who secure a STEM job after graduation by about 50%. Among those with science degrees, the number of graduates is 90% to over 100% greater than the number who enter STEM jobs after graduation (Lowell and Salzman 2007; Salzman 2013; Kuehn and Salzman 2018). In other words, colleges graduate 50% more computer science and engineering students than the number from their cohort who are hired into those occupations, and in sciences, colleges are graduating nearly double the number of science graduates than are hired into science jobs.

Historically, about 8 to 10% of each graduating BA cohort is hired into STEM jobs, or up to slightly more than half of the 15 to 18% of those who graduate with a STEM degree each year of the past four decades (with the exception of the 1986 graduating cohort, of which 22% were STEM graduates). Of course, many of those not in formally defined STEM jobs may be productively using their STEM degrees, and many non-STEM jobs may be best filled by someone with a STEM education. Even so, the supply of STEM graduates is still substantially larger than the number employed for their STEM degree qualifications. Of the *entire* workforce, approximately

[2] Comprehensive, nationally representative studies of college major and occupational entry are limited to the National Center for Education Statistics longitudinal survey "Baccalaureate and Beyond," which were for graduating cohorts in 1993 and 2008. These estimates are consistent with other data sources such as the National Science Foundation's SESTAT on similar populations. Although the 2008 cohort entered the job market during the Great Recession of 2008, the population analyzed is restricted to those who are employed. The recession may have had an impact on occupational transition (and/or employment rates), but it does not appear to have had a large impact on these historical trends identified in other cohorts.

only a third of all four-year STEM degree holders are employed in a STEM job (Salzman 2015; Landivar 2013).[3]

The supply of graduates thus appears sufficient to meet employer demand. Beyond that, the normal market mechanism of raising pay to increase hiring has historically met changes in demand.[4] Despite these realities, in recent years, a massive number of national and local programs have tried to increase the numbers of STEM students in the K-12 grades in order to increase the number of students who graduate college with STEM degrees. The K-12 STEM programs generally focus on the notion that unless the supply of STEM-focused K-12 students can be increased, the pool of students will be insufficient to expand the supply of STEM college graduates, whether for current demand or for the expectation of a large increase in future demand. These concerns often focus on middle school students, who are the subjects of national and international tests of educational performance such as TIMSS (Trends in International Mathematics and Science Study), PISA (Programme for International Student Assessment), and NAEP (National Assessment of Educational Progress) (see Suter & Camilli in this issue for more discussion of international test scores).

This narrative of both the shortage of STEM workers and the substantial career opportunities in IT has given rise to a multitude of local, state, and national organizations whose purpose is to increase the STEM pipeline of students to enter STEM fields. For example, the Obama-era President's Council on Jobs, led by technology company CEOs, proposed increasing the number of engineers graduating by 10,000 per year while, curiously, not evaluating the actual demand for engineers, nor the effect the 2008 recession might have had on engineering demand in those years. More than half of engineers work in construction or manufacturing industries, and both fields experienced precipitous declines in employment in that period.[5] Meanwhile, Code.org, one of the larger IT industry-funded organizations, has lobbied federal, state, and local legislatures to mandate coding classes in the required K-12 curriculum. It speaks to the success of these and other lobbying and advocacy organizations that the STEM shortage narrative, and the IT shortage, in particular, has been propagated so extensively that shortage claims can be made without reference to supporting evidence or specific proposals about the extent of the demand for these skills or number of workers needed.[6]

[3] There is no reliable or even reasonable method for estimating non-STEM occupations that require a STEM-degreed education, but even highly speculative estimates of jobs that might need to be filled by someone with a STEM degree still show 30 to 60% more STEM graduates than employed in those jobs. Here, we use "STEM" as excluding social sciences and adjust calculations from the Census Bureau classifications that included social sciences.

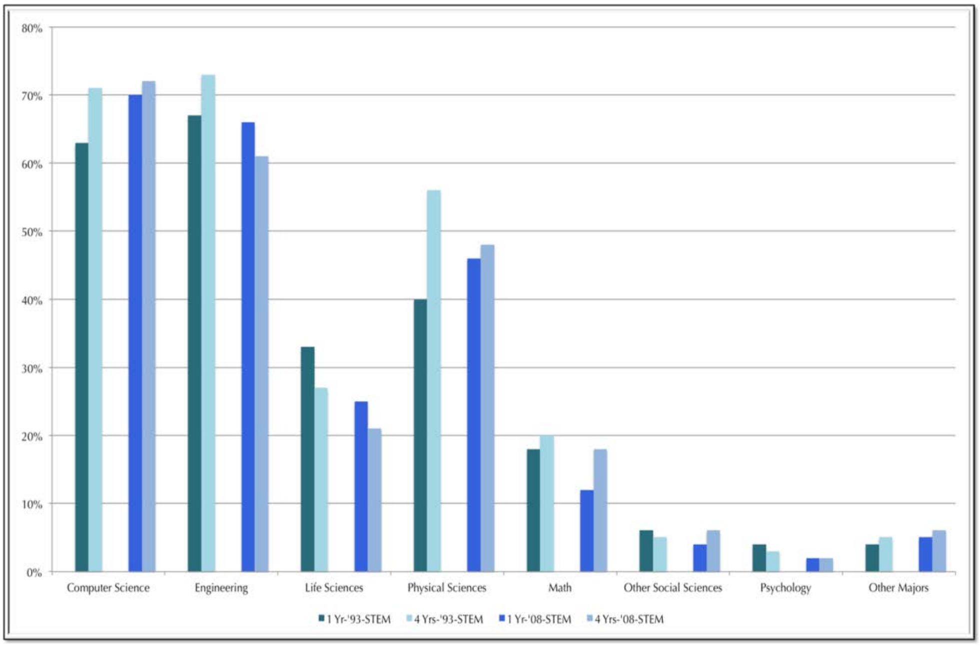
[4] See Freeman 1976 for development of the "cobweb" model of this function; see Lynn et al. 2018 for a contemporary case study.

[5] This is another case of industry executives using a public policy platform–a Presidential Advisory Council–to give credibility to a narrative of "shortages" and supposed education failures and avoiding mention of the effect of the Great Recession of 2008 (Lynn and Salzman, 2011).

[6] The computer occupations, with about 3.7 to 4 million workers, comprises approximately half of the STEM workforce, or about 2 to 2.5% of the total workforce. According to projections of IT job growth by the Bureau of Labor Statistics (BLS), the total hiring demand is for, on average, 124,000 new IT workers each year, of which there is demand for about 40,000 computer science (CS) graduates, or about two-thirds the number of CS graduates each year. Despite all evidence consistently showing college graduate supply exceeding industry hiring, Congressional testimony by Microsoft's Washington representative and counsel, Brad Smith, statements by the trade organization Code.org and echoed by the Computing Research Association, assert that college graduate supply of CS graduates is inadequate (Harsha 2014). In a notable misstatement of the BLS projections, Brad Smith testified before the Senate Committee on the Judiciary in 2013 that "The Bureau of Labor Statistics has projected approximately 122,000 new job openings each year in computing occupations requiring at least a bachelor's degree through the end of this decade. Yet nationally, our universities are only producing approximately 51,000 bachelor's degrees in computer science each year" (Smith 2013). In fact, as clearly stated in the BLS projections, these openings are for computer occupations at all education levels and fields of study, of which about one-third are for those with at least a bachelor's degree in *any* field (Landivar, 2013). Annual computer science graduation, which has grown from 38,500 in 2011 to over 65,000 bachelor's graduates in 2016, and from 19,000 to over 40,000 master's degree graduates in 2011 and 2016, respectively, produces 40-50% more graduates than needed to meet demand for new IT workers. Nevertheless, these IT industry claims are used in the widely repeated and unsupported claim of a supply shortage and of the inability of our education system to keep pace (Salzman 2013; Teitelbaum 2014).

**Fig. 2** *Bachelor's degree cohort in STEM occupations one and four years after graduation (1993 and 2008 BA cohorts)*

(Source: Author's tabulations from U.S. Department of Education (2001), Table 6; U.S. Department of Education, National Center for Education Statistics, 1992–1993 Baccalaureate and Beyond Longitudinal Study, Second Follow-up (B&B:93/97); U.S. Department of Education, National Center for Education Statistics, 2008/12 Baccalaureate and Beyond Longitudinal Study (B&B:08/12))




For an intelligent policy on STEM workforce requirements, we should ask what is the number of people to be added to the supply of potential STEM workers? And how many primary and secondary school students would be needed to achieve that goal? A first step is to consider how STEM occupational demand would relate to the student population and thus the scale needed for such programs.

For nearly a half-century, the size of the STEM cohort has increased at the same rate as the overall increase in college graduates. Since the 1970s, the cohort of four-year STEM graduates has remained a fairly steady 15 to 18% of all bachelor's degree graduates, except for a short but sharp increase in electronics engineering and computer science graduates, along with an increase in business majors, during the early to mid-1980s (see Figs. 3 and 4). That spike briefly raised the total of STEM graduates to 22% of the graduating cohort, but was followed by a collapse of employment demand for those majors caused by the high-tech recession of the early 1990s and a drop in defense spending. The numbers in those majors then swiftly declined and the proportion of STEM majors returned to the historical rate of 15 to 18% of the graduating cohort, showing the responsiveness of the system to market conditions (see Fig. 5; Kuehn and Salzman 2018; Institute of Education Sciences 2016, Table 318.20). The absolute number of graduating STEM majors increased by 237% between 1970 and 2014, closely tracking the overall increase in four-year graduates over this period.

Complicating the picture about "shortages" is the fact that STEM is a highly heterogeneous mix of fields that have little in common in terms of the type of work each entails, their disciplinary content, employment patterns, or economic cycles. In fact, even within each discipline, subfields differ quite substantially. Engineering, for example, includes both civil engineers who work largely in construction, with employment levels following construction booms and busts, and electronics engineers and computer scientists who work in the military, government, and computer industry sectors and follow economic cycles often dependent on defense R&D spending. Science fields, meanwhile, are distinct from either engineering or IT, some of them depending largely on government funding, whether directly in government labs or indirectly in university labs substantially funded by federal research grants.

**Table 1** *Bachelor's degrees awarded by major 1970–2015* (Source: Digest of Education Statistics, 2016 NCES Chapter 3; calculations by authors)

| Year | All graduates | STEM | Natural sciences and mathematics | Computer sciences and engineering | Non-STEM majors |
|---|---|---|---|---|---|
| 1970–1971 | 839,730 | 134,486 | 81,916 | 52,570 | 705,244 |
| 1975–1976 | 925,746 | 143,924 | 91,596 | 52,328 | 781,822 |
| 1980–1981 | 935,140 | 168,568 | 78,092 | 90,476 | 766,572 |
| 1985–1986 | 987,823 | 215,687 | 76,228 | 139,459 | 772,136 |
| 1990–1991 | 1,094,538 | 175,119 | 70,209 | 104,910 | 919,419 |
| 1995–1996 | 1,164,792 | 195,946 | 93,443 | 102,503 | 968,846 |
| 2000–2001 | 1,244,171 | 206,783 | 89,772 | 117,011 | 1,037,388 |
| 2005–2006 | 1,485,242 | 234,785 | 105,899 | 128,886 | 1,250,457 |
| 2009–2010 | 1,649,919 | 254,129 | 125,801 | 128,328 | 1,395,790 |
| 2010–2011 | 1,716,053 | 268,034 | 131,871 | 136,163 | 1,448,019 |
| 2011–2012 | 1,792,163 | 287,415 | 141,355 | 146,060 | 1,504,748 |
| 2012–2013 | 1,840,381 | 302,857 | 148,899 | 153,958 | 1,537,524 |
| 2013–2014 | 1,869,814 | 319,253 | 154,917 | 164,336 | 1,550,561 |
| 2014–2015 | 1,894,934 | 336,464 | 161,787 | 174,677 | 1,558,470 |

Although, as we have seen, the supply of STEM bachelor's graduates has tracked the overall increase in college graduates for the past half-century, patterns of change among disciplines have differed dramatically according to market circumstances particular to the various fields. The number of natural sciences graduates, for example, declined in absolute numbers during the 1980s but recovered in the 1990s and then increased at a steady rate through the 2000s, paralleling the overall increase in college graduates (Fig. 4). Computer science and engineering experienced a dramatic increase during the late 1970s and early 1980s, followed by an employment collapse in the defense, electronics, and computer industries (see Kuehn and Salzman 2018 for discussion of engineering and computer science employment trends and causes). Over this period, the composition of the STEM category shifted, with computer science and engineering increasing from 39% of all STEM graduates in the 1970s to over 50% after 1980, except when, for a brief period peaking around 1986, computer science and engineering accounted for nearly two-thirds (65%) of all STEM graduates. The growth (and decline) rate of STEM fields is thus both highly cyclical and unstable year to year, as shown in Fig. 6. The volatility of change of graduates in some fields indicates that students move relatively quickly in and out of fields based on perceived demand. Some of the volatility occurs because of the lag in market demand and student response, which results in supply tending to overshoot increases in demand followed by sharp decreases when graduating cohorts have difficulty finding jobs (there is about a two-year lag between increases in demand and large increases in supply and, similarly, about a two-year lag between decreases in employment and declines in graduate numbers in those fields (see Lynn et al. 2018; Freeman 1976, and Freeman and Salzman 2018 on the "cobweb" model).

**Fig. 3** *Bachelor's graduates by major*

(Source: Digest of Education Statistics, 2016 NCES Chapter 3; calculations by authors.)

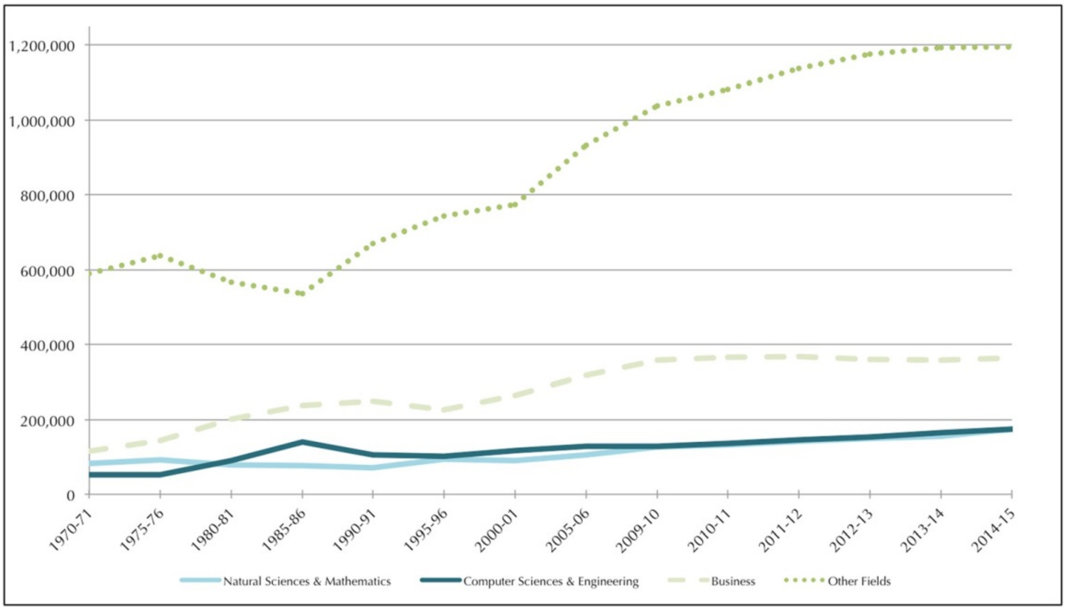
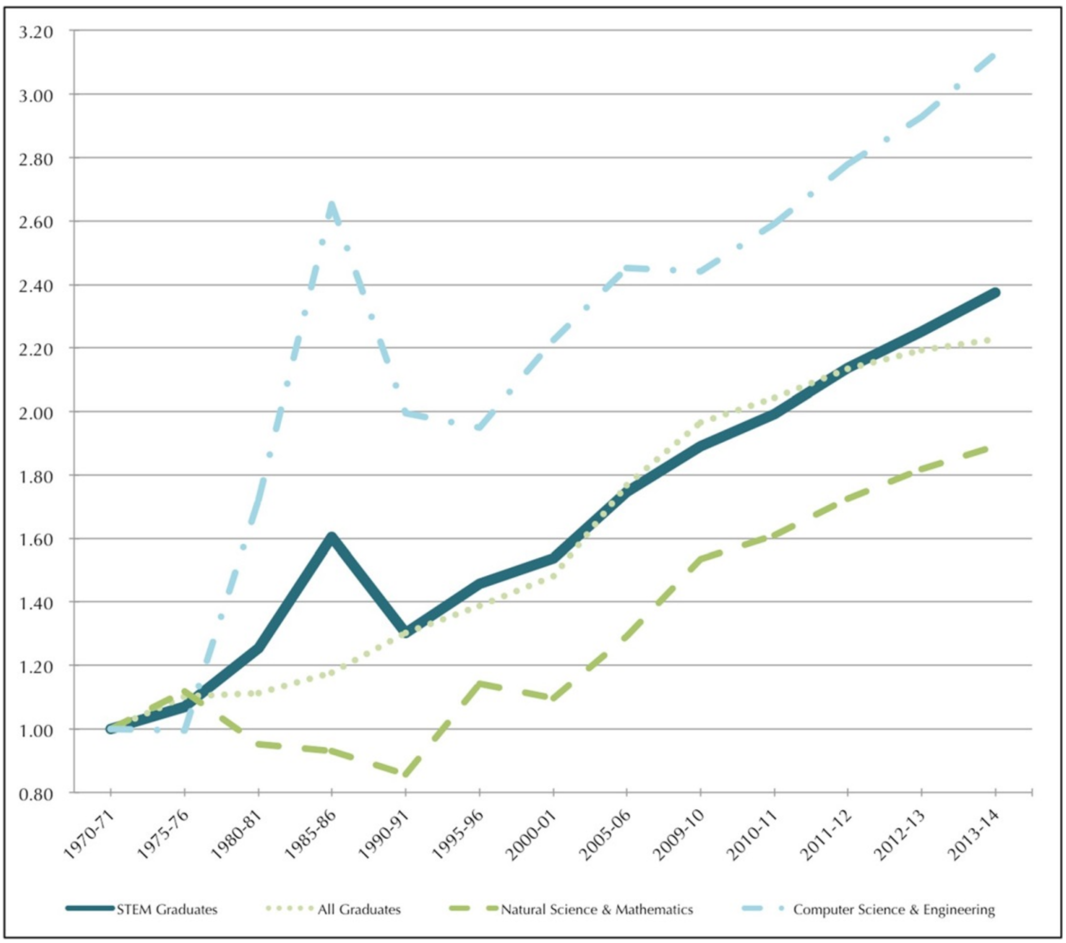



**Fig. 4** *Bachelor's degree graduates: rate of growth from 1970 base year*

(Source: Digest of Education Statistics, 2015 NCES Chapter 3; calculations by authors)



## The Supply Line

Clearly, there is no indication either that the demand for STEM graduates exceeds the supply or that the supply cannot quickly increase during brief periods of sharply increased demand (e.g., Cappelli 2012, 2015; Salzman 2013, 2016; Barnow et al. 2013; Lazonick et al. 2014; Stephan 2012). Nevertheless, ensuring a continued and high-quality supply might warrant expansion of K-12 programs focused specifically on STEM. The scale of programs to increase overall supply, as opposed to increasing diversity, as we discuss below, should take into account the size of those programs' target population. One metric for this assessment, of the "pipeline" of STEM-potential students, is the performance of the 10th-grade, or 15-year-old (depending on the testing program) student population, which is often tested for national and international educational assessments.

**Fig. 5** *Majors of bachelor's graduate cohorts* (Source: Digest of Education Statistics, 2016 NCES Chapter 3; calculations by authors)

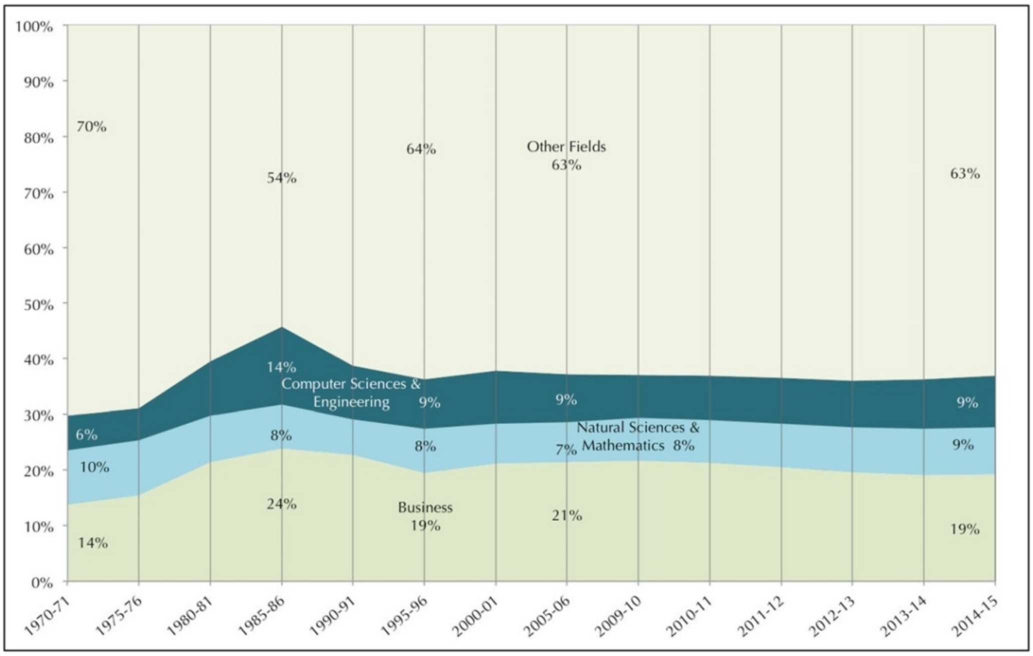
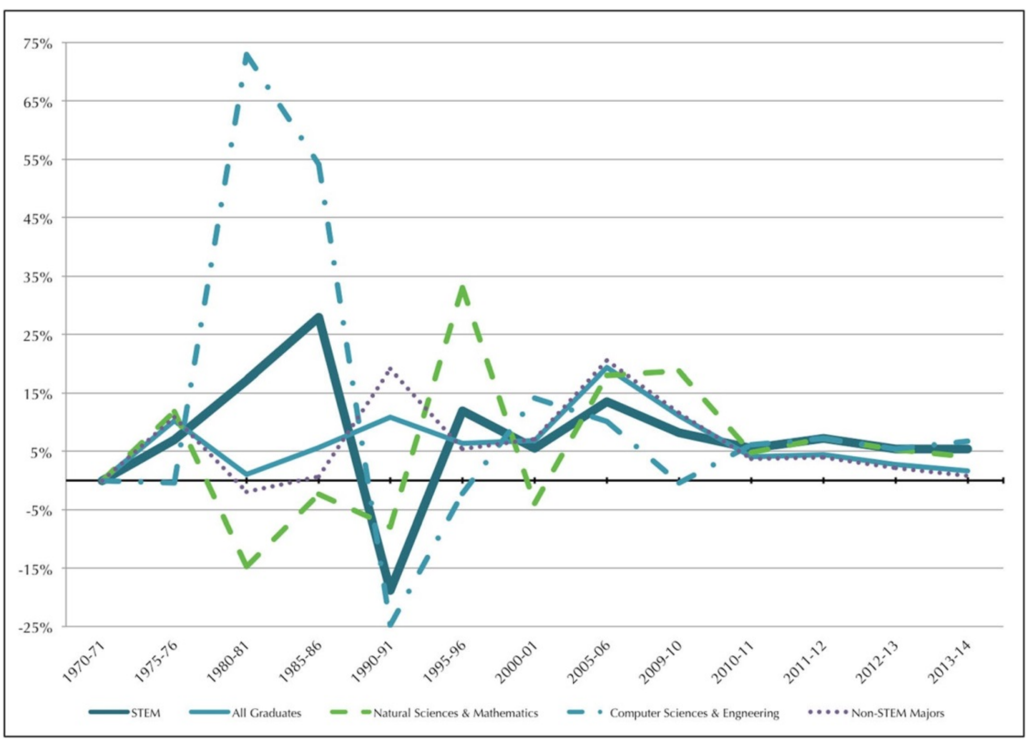



**Fig. 6** *Graduates by field: percent change from prior period* (Source: Digest of Education Statistics, 2015 NCES Chapter 3; calculations by authors)



The 10th-grade enrollments are approximately 4.2 million students; the STEM BA-graduate cohort was 336,000 in 2015, which is 8% of the 10th-grade enrollments. About 60% of STEM graduates enter a STEM occupation, which equals 4.4% of the 10th-grade cohort (Institute of Education Sciences 2016; Tables 318.20 and 201.20). Thus, continuing the current and historical share of STEM majors among college graduates into the future will require that approximately 8% of the 10th-grade cohort graduate college with a STEM major. STEM occupational demand for four-year STEM graduates is met by a "STEM yield" of 4% to 5% of that 10th-grade cohort (i.e., the percentage that continue on to college, graduate with a STEM major and enter a STEM occupation). In other words, STEM occupational demand is satisfied by less than a tenth of each student cohort entering the "STEM pipeline." (the student cohort size does not vary greatly over the grades). Absent of any indication of demand outstripping supply, apart from occasional short-term spikes in hiring, there seems to be no rationale for widespread programs focused on expanding the supply of STEM college graduates in order to meet labor market need. Students move in and out of STEM fields quite rapidly in response to changes in labor market demand (see Lynn et al. 2018, for analysis of recent changes in engineering demand and response dynamics; and Kuehn and Salzman 2018 for historical trends in engineering fields).

Although overall supply appears, by all measures, quite robust, there is, however, good reason to increase the opportunity for members of excluded demographic groups to enter STEM fields. But this is an issue of equity rather than STEM workforce supply and demand. African Americans and Hispanics, for example, are significantly underrepresented in most STEM fields. Women have reached parity or near parity with men in a number of STEM fields, including bachelor's- level mathematics,[7] and even majority status in some life sciences from the bachelor's to the PhD. level. In other STEM fields, particularly engineering and computer science, women are significantly underrepresented at the bachelor's level as well as post-graduate levels. (For analysis of changes in the supply of engineering and computer science graduates from historically black colleges and universities, see Weinberger 2018).

## STEM Skills Beyond Degrees

STEM educational achievement is important not just to fill specific occupations but important in its own right because it produces an informed citizenry. Although not determinative by itself, it is also a necessary ingredient that organizations need in order to develop innovative and productive enterprises. For these reasons, it is important to assess the state of STEM education. People in a wide range of occupations, not just in defined STEM occupations, use STEM skills. It is thus worthwhile to consider whether concerns about the levels of STEM education and STEM skills such as math among the general workforce are justified. To do so, it is necessary to examine specific disciplinary subjects rather than undifferentiated "STEM skills" that can refer to any number of subjects or levels of education.

First, let us consider the level of math skills and education used in the workplace. Michael Handel (2016) has done the most extensive research into the skill profiles of occupations, examining the specific types of skills actually used on the job. Overall he finds,

> ...most workers use relatively simple levels of math on their jobs, but there is a bifurcation of jobs in terms of the complexity of reading and especially writing that is required. Aside from managerial and professional occupations, the absolute level of academic skills required on most jobs does not appear to be very high. Likewise, computer use is widespread but most people use computers for fairly mundane office duties rather than more complex tasks; few workers use any kind of automated production equipment on their jobs (Handel 2016: 1)

[7] Since 1972 women have constituted between 42 and 48% of all bachelor's- level mathematics graduates and have gradually been increasing their proportion in graduate programs. In recent years, women received 40% of the 6000 to 7000 master's degrees in mathematics awarded each year, but only 29% of the 1700 to 1800 PhDs in mathematics.

In terms of STEM skills such as mathematics, he finds that beyond the two-thirds of workers who use fractions, decimals, and percentages, only 22% use more sophisticated mathematics, typically simple algebra, and that this mathematics usage is concentrated in the skilled trades. In short, most people do not even use the types of mathematics taught at the high school level, with 10% of workers using inferential statistics and/or advanced algebra and only 5% using calculus. Another assessment of math education by Andrew Hacker (2015) arrives at similar conclusions, noting that the higher levels of mathematics emphasized by many STEM education efforts, such as calculus or trigonometry, do not provide the math skills required in most jobs or for general literacy. Along with Handel, Hacker suggests that the demand for higher-level skills is far more limited than commonly asserted. Douglas and Attewell (2017) find that higher-level math classes are more likely to be used as "signaling" than for specific occupational or even academic applications.

Although the occupational demand for higher-level mathematics skills may be more limited than often suggested, there is nonetheless widespread use of some mathematics in work as well as in everyday life to understand everything from medical treatments to consumer product ratings. Focusing on college graduates and STEM skills that might be needed outside of formal STEM occupations, we examined the extent of college course-taking in mathematics as one indicator of the extent of STEM education in the college-educated labor pool. What, in other words, is the level of math education among college graduates in light of employer demand for math skills and the use of those skills outside of STEM occupations?

In a comprehensive, in-depth analysis of math course-taking by college graduates, Douglas and Salzman (2019) find that math course-taking varies widely among STEM majors. STEM life science majors take an average of 11 math credits, physical science and computer science majors average 18 credits, engineering majors average 23 credits, and math majors average 49 credits. They also found that a large number of non-STEM students also complete a substantial number of math courses. Using the median number of math credits taken by STEM majors as an indicator of "high-intensity" math course-taking, they found that the population of non-STEM students with high-intensity math credit levels is 15% larger than the number of STEM students who exceeded the median. That is, there are more non-STEM than STEM majors with high levels of math course completion. Overall, non- STEM students take two-thirds of all math credits earned by BA graduates.

The numbers of STEM courses that students take varies widely both among STEM majors and among those in non- STEM fields. Among STEM majors, engineering stands out for both the high numbers of STEM courses that students take and the heavy credit loads they carry overall. About 90% of engineering majors graduate with more than 90 STEM credits. Only about a third of other STEM majors graduate with more than 90 STEM credits, with a median of 83 earned STEM credits. However, 24% of math and 15% of computer science majors earn fewer than 60 STEM credits. Computer Science has the broadest STEM credit distribution of any STEM major, indicating that STEM content of Computer Science degrees varies more than in other majors. Many Computer Science majors do not appear to have a high concentration of STEM courses, illustrating the large range in STEM course-taking among STEM majors.

Students in non-STEM fields, meanwhile, achieve much greater levels of STEM education than suggested by a focus solely on their majors. All STEM graduates earn a minimum of 30 STEM credits, but among the much larger overall population of non-STEM students, the number of those graduating with at least that minimum of STEM credits is 50% larger than the number of STEM majors who take that many STEM credits. Non-STEM majors who have at least as many STEM credits as the 30 credit minimum required for a STEM degree number 294,000, as compared to 193,000 STEM majors in the graduating cohort. As would be expected, although many students not majoring in STEM fields meet the credit requirements for a major in a STEM field, they are concentrated at the lower end of the STEM credit distribution. Nonetheless, more than a quarter (27%) of the BA cohort earning a moderate or high level of STEM credits (61 or more STEM credits) are non-STEM majors; excluding engineers, non-STEM students comprise 37% of the graduating cohort with moderate or high levels of earned STEM credits.

In summary, the analysis of the STEM credits that students earn finds that, with the exception of engineering, the extent of STEM education varies widely both within each STEM major and among different STEM majors. Moreover, a large number of non-STEM graduates earn STEM credits on a par with STEM majors. Clearly, any discussion of STEM education needs to look beyond focusing on an aggregate “STEM major” category to examine the STEM composition of students’ education rather than the label of their majors. Further, sweeping assertions about STEM education levels are too broad to have analytic utility for assessing the extent of STEM education among college graduates or the size of the graduate pool who have a STEM education.

## Lagging Performance?

Another component of the STEM shortage claims focuses on a narrative of declining educational performance (notably the National Academy report, *Rising Above the Gathering Storm*, which has been widely cited; see Salzman 2013; Lowell and Salzman 2007, for discussion of these claims). Although the supply of STEM graduates and workers is more than adequate—the STEM college “pipeline” reaches its capacity with only 8% of the K-12 student population and a mere 4 to 5% of each K-12 student cohort will satisfy BA-level STEM labor force demand—a broader demand for STEM skills may still exist. Although STEM education among college graduates may be more widespread than typically assumed, and workplace STEM demand, as Handel (2016) and others have shown, is more limited in scope than the STEM shortage and educational decline narratives suggest, STEM knowledge is still needed both in the workplace and for functioning as an educated citizen. It is important to thus consider the educational performance of the overall student population.

Students in high schools since 1990 have steadily increased the number of STEM course credits completed. High school graduates in 1990 completed an average of 3.2 mathematics and 2.8 science credits, as compared to 3.9 mathematics and 3.5 science credits completed by the graduating high school cohort of 2009.

The mathematics and science achievement levels have also increased over the past decades. In terms of the supply of STEM-potential students, the increased share of students who are performing at high levels is more important than the average performance of the entire population. (As noted above, only about 8% of a high school cohort is sufficient to maintain the historical share of STEM college majors). Assessing overall performance, including that at the lower levels, is vitally important for evaluating education levels generally, but is less relevant for STEM workforce development. The share of students with proficient or advanced mathematics achievement levels has increased from 15 to 33% of the student population from 1990 to 2015 (Fig. 7) and the share of students at proficient and advanced levels of science increased from 31 to 34% from 2009 to 2015 (science was not tested prior to 2009; see U.S. Department of Education, 2015).

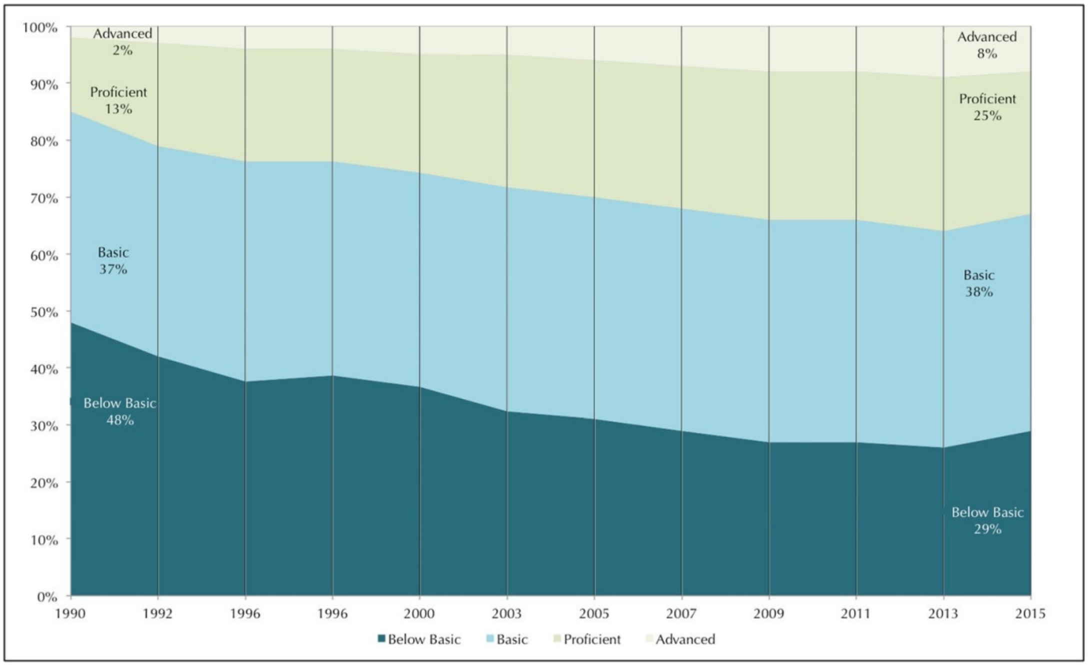
## Gaps and Improvements: Ecological Fallacies and the “Improvement-Impact” Paradox

Although additional improvements in education are needed, the evidence does not suggest any particular problems in the supply of STEM-potential students as measured by overall academic achievement. Instead, strong evidence indicates steady and substantial progress. Overall improvements, however, do not necessarily translate into improvements for all groups or individuals. Perhaps most importantly, even high levels of improvement may have limited impact because, at best, they can effect only slow, incremental change. As we will discuss, the direct impact of schools on educational performance is quite limited compared to the impact of non-school factors such as socioeconomic status.

Further, considering *overall* performance does not indicate either the size of the STEM-potential population in various demographic subgroups or the reasons that some groups are underrepresented in STEM fields. Assessing the STEM- potential population and the impacts of educational performance in different demographic groups requires assessing the distribution of skills and education rather than just noting aggregate performance metrics. Importantly, evaluating the relative educational trajectories of particular demographic groups requires comparing their relative change over given periods of time as well as the expected range of change for the groups and the effect size of educational improvements. These two factors, changes in the distribution as compared to changes in mean outcomes and the assessment of significant improvements that can be expected to have only small impacts on educational performance, are important for understanding the STEM supply and progress in education and the outcomes for different demographic groups.

The stylized facts are that some demographic and lower-income groups have lower test performance and these performance gaps, especially between white students and black and Hispanic students, have persisted despite educational reforms.

**Fig. 7** *Mathematics achievement levels 1990–2015 (8th grade)* (Source: National Assessment of Educational Progress, National Center for Education Statistics, National Assessment Governing Board, Institute of Education Sciences, U.S. Department of Education)




An extensive body of research considers potential causes of demographic performance differentials, ranging from discrimination to socioeconomic status. The racial and income disparities are quite large and these educational deficits are rightly considered substantial problems that have persisted over time, as shown in Fig. 8. Two data points—the lower test performance of minority groups and the persistent gaps in the groups' average test scores—typically lead to conclusions about the education system's failure and its inability to develop an adequate supply of STEM-potential students. Although the education system may be failing particular groups of students, average test performance scores do not fully represent the nature of the problem.

First, we must consider that schools, in and of themselves, are known to affect educational performance by a fifth or less of measured outcomes. That is, a host of non-school achievement factors, such as poverty, parents' education, and other aspects of the students' and the schools' community environment have a far greater impact on educational outcomes than the schools themselves (e.g., for review, see Reardon et al. 2017). Thus, we must consider effect size and the extent of change over time relative to the impact schools have on these outcomes. If, for example, schools can affect 20% of performance outcomes on average, and a given program increases performance by 15% in a year, that leads to an overall annual improvement of 3%. A given group might achieve greater gains because it has a different base rate; greater unrealized potential, which increases the school's potential effect on that group; or greater resources or effort that were devoted to improving the performance of a lower-performing group of students. Unless higher-performing groups achieved far less improvement, however, closing a gap of this magnitude would take a very long time. Simultaneous improvements of all groups can even lead to *widening* of the achievement gap, in which case achievement gains of the lagging group may become measured as failure.[8] The persistence of an achievement gap should be a reason for concern, but it is not the same as a failure to create any improvement. Failures of convergence are quite different from failures in improvement.

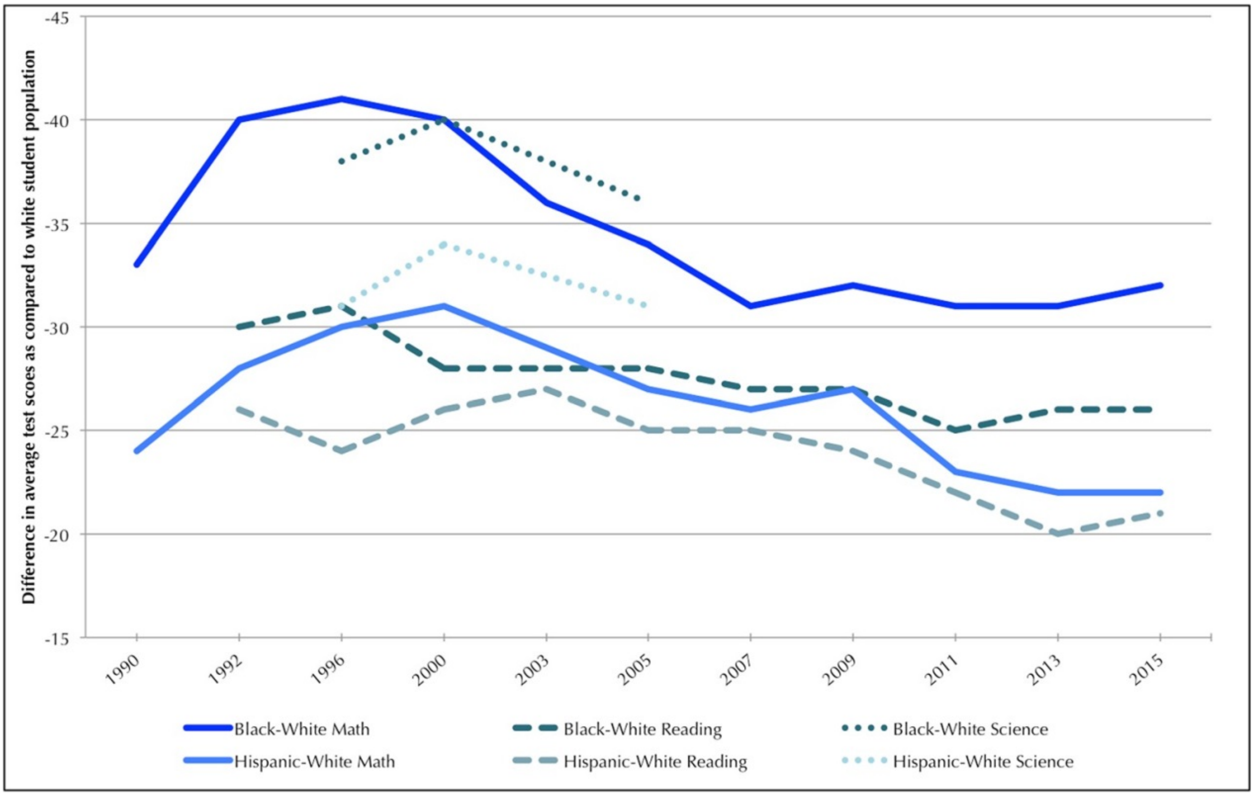



**Fig. 8** *NAEP test score gaps by race*

(Notes: For reading, tests were given in 1994 not 1996; 1998, not 2000; science was tested only in 1996, 2000, and 2005. Black includes African American, Hispanic includes Latino, and Pacific Islander includes Native Hawaiian. Race categories exclude Hispanic origin. Prior to 2011, students in the "two or more races" category were categorized as "unclassified." Some apparent differences between estimates may not be statistically significant. The standard deviations ranged from 34 to 38. Sources: Author's calculations based on: U.S. Department of Education, Institute of Education Sciences, National Center for Education Statistics, Selected years: NAEP, 1992– 2015 reading assessments; NAEP, 1990–2015 mathematics assessments; NAEP, 1992–2015 reading assessments)

[8] As a hypothetical example, if two groups score 260 and 290, respectively, of which schools can affect 20% of the performance and schools of both groups achieve 15% improvement annually for 10 years, the gap would actually increase from 30 to 39 points; if the lower group's schools improved by 20% annually and the higher (290 base score) group's schools improved by only 15% annually, after 10 years the gap would be reduced to 8 points.

In assessing success or failure of schools, therefore, expected change should be based on the range of known effect size, as would be the case in any performance assessment. The intention is not to affirm low expectations but rather to establish meaningful metrics for assessment. In addition, examining the absolute and relative changes in subgroup populations is necessary to avoid ecological fallacies. In this case, the persistence of performance gaps, while undesirable, must be assessed in the context of a dynamic system undergoing simultaneous changes.

The performance gaps separating white students from black and Hispanic students has been longstanding and persistent, ranging from 20 to 40 lower test score points (Fig. 8). At the same time, progress, albeit slow, has been closing the gap. The persistence of a gap cannot, *ipso facto*, be attributed to school failures without considering why the gap persists and what the schools contribute to its persistence. Studies of the determinants of test outcomes find socioeconomic status and race to be significant and persistent determinants of these gaps (Vanneman et al. 2009; Musu-Gillette et al. 2017; Bohrnstedt et al. 2015; Rothstein 2015; Rothstein, 2017). These studies discuss the complexity of the problems of inequality, education, and test performance outcomes. Nonetheless, these racial and socioeconomic status achievement gaps persist despite progress in reducing them. Given overall improvements in achievement, lower-achieving groups would need to outpace the improvement rate of the higher-scoring groups in order to close the gap. That, however, is a problem distinct from a failure to improve. Evidence suggests that educational reforms have had a positive and significant impact, even if a smaller one than desired (Baker and Weber 2016). As shown in Fig. 9, secular improvements occurred in all subjects by all racial groups over the past 25 years. African Americans and Hispanics achieved even greater rates of improvement than whites in some subjects, but closing these test score gaps would require still greater improvements by the lower-scoring groups than those achieved by the higher- scoring groups. The lower absolute levels of achievement would indicate the need for those greater improvements and targeted efforts to achieve them, but in the context of overall educational gains, closing that gap becomes a moving target. Further, the predominant finding of educational studies is that non-school achievement factors account for a large share of performance outcomes and changing these factors requires interventions far beyond the schools. Schools can play an important role, but the evidence does not indicate that schools, alone, account for a large share of the determinants of outcome differentials.[9]

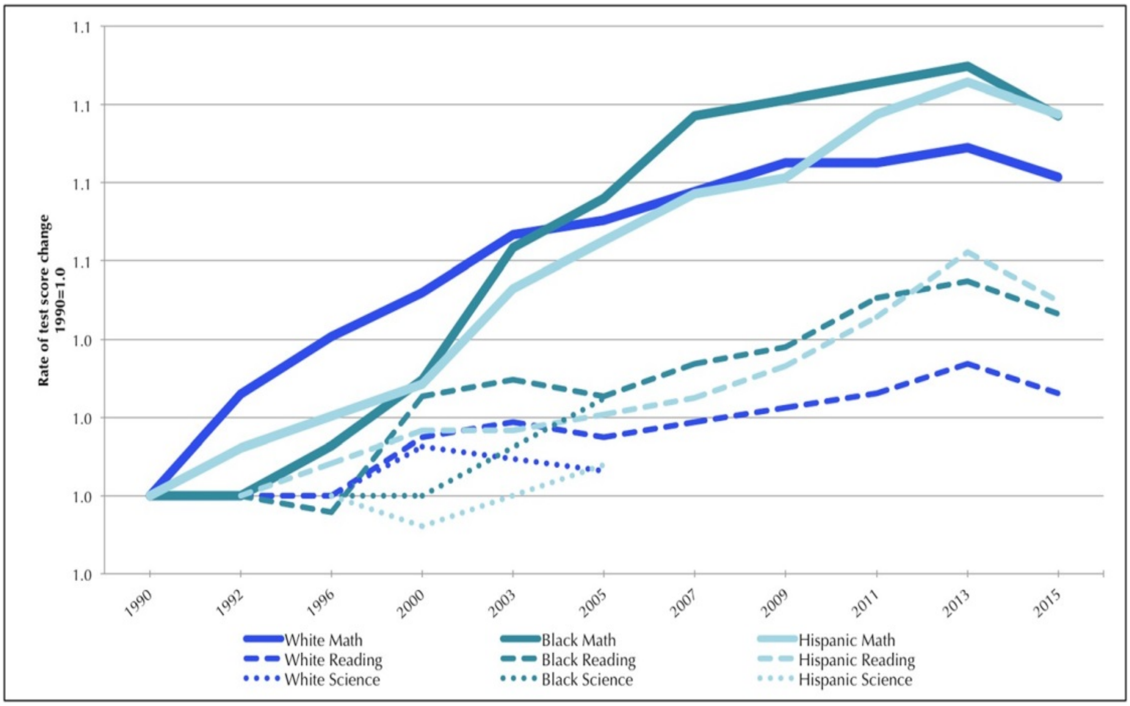
Lower aggregate performance of some demographic groups will, *on average*, limit the pool of STEM-potential students from those groups. However, given the small numbers of students in those groups who are in STEM fields, and who are drawn from a very small share of the overall distribution, it is unclear to what extent aggregate test scores indicate limitations in a STEM-potential pool that would explain the large differentials in the rates at which students in these groups enter STEM careers. That is, given the performance improvements that have been achieved, the broad range of performance outcomes that exist, and the small numbers of students who major in STEM in college and are hired into STEM occupations after graduation, more detailed analysis is needed to determine the extent to which aggregate test performance averages can account for barriers to entering STEM. Further, educational, mentoring, and advising programs targeted at particular underrepresented students, as well as programs that address non-school achievement factors, could increase the STEM-potential pool of underrepresented students independent of overall educational outcomes of those demographic groups. Thus, average performance levels and achievement gaps are important to consider when assessing overall educational disparities but are not sufficient to assess the determinants of STEM barriers to STEM entry for these groups. Further, test score gaps are not necessarily indicative of educational failures: if all groups are improving, then gaps can remain at the same time as significant improvements are achieved and, importantly, even large changes in schools alone will have only small impacts on educational outcomes because these outcomes are

[9] There is an extensive body of research examining these issues and we are not suggesting that schools are ineffective but, rather, expecting schools to have large impacts on education outcomes overall, or on specific differentials such as racial achievement gaps, is unsupported by the research.

predominantly affected by non-school factors. Assessments of school performance, such as demographic performance gaps, need to be considered in the context of the dynamics of simultaneous change and the small share of variance in education outcomes that can be attributed to schools.

**Fig. 9** *Test score change by racial group and subject*

(Ibid.)




## Global Context of U.S. Student Performance

U.S. students' supposedly lagging performance in the "international STEM competition" is perhaps the most widely and persistently cited canard about U.S. schools. Elsewhere, we have presented the detailed analysis of the misinterpretation of international test comparisons (Lowell and Salzman 2007; Salzman and Lowell 2008), as have others (Berliner and Biddle 1997; Ramirez et al. 2006; Zhao 2009; Carnoy and Rothstein 2015; and more recently Hacker 2015; Komatsu and Rappleye 2017; Suter and Camilli in this issue). In addition to methodological limitations indicating that between-country test scores are non- comparable metrics, PISA researchers state quite unequivocally that these test results are *not* reflective of the cross-national differences in educational performance of schools.[10]

The PISA researchers explain that the tests are not measuring school performance:

PISA is not an assessment of what young people learned during their previous year at school, or even during their secondary school years. It is an indication of the learning development that has occurred since birth (OECD 2004: 198).

Thus, when interpreting results, it is important to understand that the PISA researchers themselves state that metrics based on *average* test scores and national rankings are neither designed to, nor methodologically capable of, measuring

[10] The PISA organization does not appear to try to correct these misrepresentations of their findings and, in fact, often appears to promote these unsupported assertions in presentations and dissemination materials such as press releases; in particular, the rankings that are presented as meaningful ordering of performance levels fail to note that rather than a rank ordering of countries, the results should differentiate only between statistically significant differences. In other words, a "statistical tie" is, analytically, the same ranking. Using the statistically appropriate comparisons, the United States places in the second-ranked achievement group, though even that is a flawed measure, as discussed here.

the performance of schools (Adams 2003: 381). Thus, inferences about school quality in different nations cannot be supported by the findings from the international test rankings.

Importantly, the PISA researchers find that "[n]ine- tenths of the student performance variation in PISA is within countries...differences between countries represent only about one-tenth of the overall variation in student performance" (OECD 2004; 160). They conclude that differences in the schools or education systems, in and of themselves, do not account for observed differences in performance outcomes. That is, consistent with the long-standing findings in education research, the PISA researchers also find that differences in socioeconomic background and other non-school achievement factors are the primary causal factors accounting for the differences in test score outcomes. As to improving performance outcomes, they conclude:

> Improving quality and equity therefore require a long- term view and a broad perspective. For some countries, this may mean taking measures to safeguard the healthy development of young children, or improving early childhood education. For others, it may mean socioeconomic reforms that enable families to provide better care for the children. But in many, it can mean efforts to increase socio-economic inclusion and improve school offerings (OECD 2004: 198).

Nevertheless, there is a large and constant repetition of the United States' rank order as evidence of imminent global decline, accompanied by intense scrutiny of schooling systems such as those in Singapore or Finland. These reports and news accounts focusing only on narrow schooling practices in these countries, such as length of the school day, testing, or building design, seem untroubled by the erroneous interpretation of what these tests are measuring, while steadfastly minimizing if not ignoring the conclusions of the international testing researchers. Although sweeping statements linking economic performance and competitiveness to average educational performance as measured by tests such as PISA have been a constant element of discussion (e.g., Tucker 2011), the relationship between test scores and innovation or other aspects of STEM development is noticeably weak by any direct measure. Moreover, the metrics do not reflect the outcome of school characteristics or performance, per se, and the metrics themselves are, at best, of an unknown relationship to economic and innovation outcomes. Ramirez et al. (2006), Komatsu and Rappleye (2017) and others have shown that a country's economic growth and innovation are not causally related to test scores, and in fact, it is likely that test performance and educational improvements are the *outcome* of national development programs in which educational investments are coincident with broader programs of investment in industry, health, and other growth-related factors.[11]

In the past decade, in addition to Finland, countries such as Singapore, Estonia, Slovenia, and Switzerland have topped the list of nations performing well on tests. The major economic and innovation challenges to U.S. industries have, however, come from other places, including such historical test laggards as Germany (OECD 2011). Historically high- scoring Soviet states seemed to have provided little help to the former USSR's economy or to the economies of post- Soviet countries today. Testing a national sample of students in China — rather than a selective group of students in a few cities — would undoubtedly reveal low average scores, given the country's wide educational and social disparities, and critiques of their education system further call into question claims about any school-based advantages (e.g., Zhao 2009). A further error in the conclusions of the international testing advocates is that, even by their own measures, the United States has a large supply of students fully capable of succeeding in STEM education and occupations. If we take test performance as indicating the nation's potential supply of STEM workers for industry, science research, and related innovation activities — in itself a questionable supposition even if the tests had validity in measuring comparative academic achievement — we again need to consider the comparative size of the STEM-potential pool of students, not the average performance or other attributes of the general student population. The notion that a country's level of performance on tests, whether of its student population at large or of its highest achievers, indicates the

[11] As Ramirez et al. (2006:15) explain: "...much of the achievement 'effect' is not really causal in character. It may be, rather, that nation-states with strong prodevelopment policies, and with regimes powerful enough to enforce these, produce both more economic growth and more disciplined student- achievement levels in fields (e.g., science and mathematics) perceived to be especially development related."

country's "competitiveness" and attractiveness for STEM industries is one of the most prevalent of the erroneous comparative analyses of STEM education. Observers argue, for example, that Finland's historically high average test scores indicate that country's ability to expand its STEM industries to the detriment of the United States. According to this notion, the 5.5 million people living in Finland can better support technology industries than the vastly larger U.S population. And we need not rely on educational tests as a proxy for its technology competitiveness but can look directly at its performance: Despite some notable technological successes in Finland, the spotty history of its technology companies belies its global prowess as a long-term high-tech "competitor".

The relative "attractiveness" of a country's labor force to employers arises from multiple factors, including, for a STEM industry, the available supply—that is, the total numbers—of workers with the requisite skills, education, and abilities. So, even if test scores alone indicate a workforce with STEM potential, it is not clear why companies would choose Finland or Singapore, each with about 5.5 million people, or Estonia, with 1.3 million, rather than Massachusetts, with its 6.8 million residents, Minnesota with 5.3 million, New Jersey with 8.8 million, or any of the other U.S. states whose students' scores equal or exceed those of the leaders of the international comparisons. It is not the relative average test scores that are important to a company seeking a high-performing workforce, but rather the absolute size of the workforce with the skills and capabilities it needs.

A more useful comparison between the size of the United States' potential STEM workforce and those of other industrial countries—and ignoring the pitfalls of using PISA test scores as a valid indicator of such comparisons (again see Lowell and Salzman 2007; Carnoy and Rothstein 2015)—would focus on the size of the high-performing student population among the countries with the highest PISA results. Assuming that a STEM company was seeking to locate in a country that provided a large supply of high-performing students, what share of high- performing students do various countries possess? We calculated the number of high-performing students in the leading Organisation for Economic Co-operation and Development (OECD) countries that participate in the PISA tests and in the United States and then calculated the share of that total group of high performers found in each country. In other words, in which of the PISA countries with high average scores would a company find a large population of high-performing students? The United States does quite well in this comparison, as shown in Fig. 10. Though Japan bests the United States in mathematics, a decade or more of lagging Japanese economic performance belies any conclusion that test performance translates into economic growth. Korea, on the other hand, has a large share of high-performing mathematics students but many fewer high-performing science or reading students. Nonetheless, it has done quite well economically, though the driver of its development is primarily attributed to its centralized, family-based Chaebol industrial program along with large investments in its education system (Amsden 2001). Finland, Estonia, Slovenia, Singapore (combined population of 14.4 million), and others leading the PISA lists can offer only small numbers of high-performing students to companies expanding their STEM workforces. And to the extent that their workforces support those countries' high levels of economic performance, it is not clear why that poses a threat to the United States (see Lynn and Salzman 2006, 2010 for discussion of the fallacy of techno-nationalist policies and zero-sum policies of science and technology development; see also Gomory and Baumol 2000).

The illogic of international test comparisons as indicators of economic competitiveness, and of STEM capacity, in particular, persists for ideological and political purposes rather than as a serious research project. After decades of warnings that lagging international test performance signals declining U.S. economic competitiveness and innovation, as well as the persistence of downward economic trends in the nations with the leading test scores, suggest that factors far different from those that the comparative tests measure determine a country's economic and technological performance. Little evidence suggests much of a relationship in advanced industrial countries between test performance metrics or the numbers of STEM graduates and a nation's economy (Lynn and Salzman 2006, 2010). Moreover, these international tests show the United States having the lion's share of the world's highest- performing students (Fig. 10; Salzman and Lowell 2008).

## Demand, Supply, and Shortages

Economists typically regard a long-term shortage as an impossibility: market responses to increased demand should either cause prices to rise sufficiently to induce the creation of more supply or to dampen demand. Short-term imbalances are to be expected in any market; however, in high-skill labor markets, a distinct lag will occur because it takes time for people to get the education or training required to develop the skills that are in demand (Freeman 1976; Lynn et al. 2018 found in the case of petroleum engineers a lag of about two years). In high-skill labor markets, labor is less interchangeable than in other labor market segments because of the specialized training and the barriers to students quickly shifting fields in college or completing high-skill training programs. Thus, even if demand does not exceed supply currently, the nation has an interest in assuring both a sufficient supply of students with the STEM potential needed to respond to changes in demand over the long term as well as an adequate "reserve" to be available to respond to short-term supply increases.

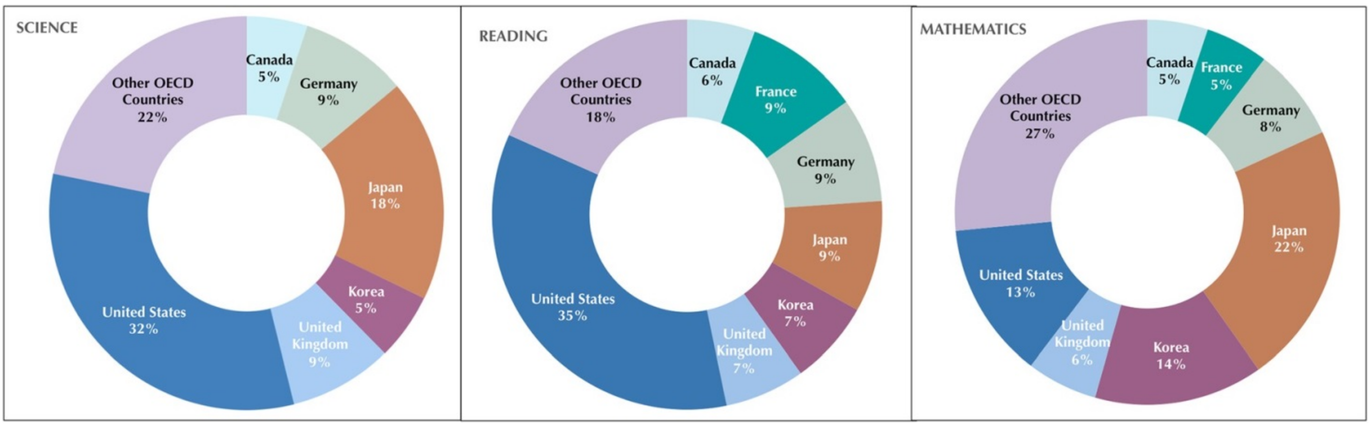



**Fig. 10** *Share of selected OECD high-performing students by country, 2015*
(Source: These figures are based on analysis in: Salzman and Lowell, 2008; "Making the Grade" *Nature* 453, 28–30; updated using PISA 2015 test results of students at Level 6, scoring approximately two standard deviations above the overall OECD mean.)

At the same time, labor market experts, legal scholars, and policy makers overwhelmingly agree that market interventions should not be focused on increasing supply to just lower labor costs and undermine normal market mechanisms (e.g., Naidu et al. 2018). Still, STEM fields warrant special attention from policy makers to support workforce development because a number of them are generally deemed crucial for the economy and the national interest. In addition, policy makers have an important role in ensuring opportunity and diversity in this labor market given the history of discrimination, exclusion, and imbalances in STEM workforce demographics.

Evidence should guide the level of policy intervention in STEM labor markets. Determining the relevant evidence and the appropriate metrics is not straightforward, however. What is the appropriate size of the STEM-potential population at K-12 levels to support future demand? What are the metrics for assessing the STEM-potential student population?

This analysis addressed these questions by analyzing multiple metrics and historical trajectories of STEM supply. The preponderance of evidence based on multiple metrics supports several key findings. First, the college graduate STEM workforce draws from a very small segment of the general student population, about 5% of K-12 student cohorts and 8 to 10% of the annual supply of college graduates. Colleges historically produce between 40 to 100% more STEM graduates, depending on the field, than are hired into STEM occupations each year. Second, educational performance as measured by national and international tests shows steady and consistent increases in performance by all groups. Beyond that, as compared to other nations, the United States produces a large share of the world's high-performing students. Third, particular labor markets such as petroleum engineering (Lynn et al. 2018) and IT (Salzman et al. 2013) have experienced large fluctuations in demand over the past half-century and, as shown here, STEM fields have exhibited large changes in supply during both expansion and contraction cycles. College students appear to move fluidly between fields in response to changes in labor market demand. Fourth, the level of STEM education is much broader than merely counting just those graduating with a STEM major would indicate. Large numbers of non-STEM majors graduate with mathematics and science credit levels on par with, or above, the median level of STEM majors; in fact, the number of non-STEM majors is equal to, and often exceeds, the number of STEM majors with high levels of mathematics and science course credits.

In summary, the preponderance of evidence suggests that the U.S. education system has produced ample supplies of students to respond to STEM labor market demand. The "pipeline" of STEM-potential students is similarly strong and expanding. While this analysis finds no evidence to justify concern about overall supply, it does indicate areas where some demographic groups are not adequately represented. Given the small numbers employed in STEM fields and the overall improvements in educational performance, it is unlikely these deficits result from any systemic inability of the education system to develop a sufficient supply of STEM- potential students or workers in various demographic groups; rather, the barriers more likely lie in characteristics of the demand side, of employer hiring practices. Finally, these findings about the substantial size of the STEM-potential student population and the ability of students to respond to labor market demand suggest little need to establish programs to artificially expand occupation-specific programs or to narrow the educational curriculum in an effort to concentrate on STEM.

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