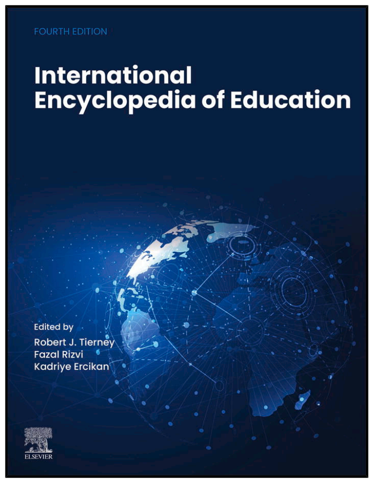

From Salzman, H., Douglas, D., 2023. In: Tierney, R.J., Rizvi, F., Erkican, K. (Eds.), International Encyclopedia of Education, vol. 11. Elsevier.
https://dx.doi.org/10.1016/B978-0-12-818630-5.13065-9.
ISBN: 9780128186305

Elsevier

STEM education and workforce development: the history, politics, and evidence

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The global nexus of STEM education and workforce development

STEM workforce development is at once a nation-specific and a global enterprise. A nation's competitiveness and level of development are typically considered dependent on the strength of its science and technology capacity (e.g., Romer, 1994), and thus policy makers focus on various metrics about a nation's STEM workforces as indicative of its economic prowess. Similarly, the global migration of students and high-skilled workers has become an issue of national and international policy: "Receiving" countries encourage immigration into their colleges and STEM workforces, while "sending" nations view the loss of their potential workforce as a continuation of brain drain. However, some nations, such as India, have found global migration important for their outsourcing technology industries, or in the case of China, as a means of developing a high-skill workforce trained in cutting edge technology and science that can be recruited back to contribute to its own economic and technological development (Lynn et al., 2012; Lynn and Salzman, 2018; Meil and Salzman, 2017; Saxenian, 2006).

Although STEM workforce development systems are integrated into a global network, they function differently around the world depending on the structure and quality of each nation's education system and the types of businesses in each country, along with national policies. Moreover, perspectives differ on whether each country's STEM system provides global or only national benefits. This debate has become a contentious public policy issue in the United States, where large global flows of STEM students and workers have become an integral component of its STEM workforce system. But too often these policy debates rest on simplistic notions about the role of STEM education and the STEM workforce, along with misconceptions about "national competitiveness" in these global systems. As a consequence, STEM and education policies often have the paradoxical effect of undermining a nation's, and the world's STEM workforce development and capacity.

Historically, nations benefitted from migration that contributed to their economic and social development and the STEM fields, in particular, benefited from selective global migration. In recent years, the creation of targeted and nonimmigrant education and work programs has again become a matter of policy and legislative debate. Scholars and lawmakers question whether some transnational flows of students and workers are counterproductive to the nation's indigenous STEM strength—either in loss of workers or in weakening labor markets in the receiving countries (Borjas, 2016) even if large supplies of guestworkers are profitable for individual firms. For example, the US Department of Labor calculates that the H-1B nonimmigrant temporary visa program, by supplying technology guestworkers at below market wages, creates a transfer payment from forgone worker wages to employers of $3 billion to $4 billion annually (Employment and Training Administration, 2021). As such, historical patterns of STEM education and workforce development may be changing, with different impacts from those of the past.

Further complicating simple formulations about the role of STEM workforce development in a nation's economy is the complex nature of global interdependencies in technology development. In the US, simplistic analyses have used metrics such as the number of engineering graduates to assess a country's presumed advantage or "competitiveness." The use of such indicators has led to dramatic proclamations: first, that the Soviet Union's large math and engineering cohorts would enable it to overtake US science and technology innovation; then a fear that Japan's prodigious engineer production would lead to its global dominance and, in the past decade, fears that China's large number of engineering graduates will imperil US competitiveness (National Academy of Sciences et al., 2007; Teitelbaum, 2014). In these cases, the reports used questionable metrics and comparisons (Berliner and Biddle, 1997; Salzman and Lowell, 2008) but, more importantly, they failed to consider the role of different STEM workforces in each

 https://doi.org/10.1016/B978-0-12-818630-5.13065-9

International Encyclopedia of Education, Fourth Edition, 2023, 358–369

country's development. The number of engineers, for example, largely reflects the amount of construction in the country, however building roads, housing and factories is not considered an indicator of a nation's "global competitiveness" or innovation capacity (Lynn and Salzman, 2010; Kuehn and Salzman, 2018).

At the same time, a globally integrated STEM education system can provide strong global linkages in innovation networks, can facilitate the "sending" country's development through educating and training its workforce, and/or can contribute to global networks that enable outsourcing and offshoring. Such globalization can increase the fortunes of a firm while weakening the economy or welfare of its home country. Although the global STEM development system depends on industrialized countries' STEM education systems to supply globalized STEM enterprises, those "host" countries may not be the beneficiaries if firms globalize work or engage in global labor arbitrage to lower wages (Hira, 2008; Lynn and Salzman, 2018).

There is another challenge in aligning STEM education and workforce development: educational institutions vary greatly between and within countries, as do pedagogical practices. But STEM disciplines are assumed to largely, or at least conceptually, transcend national borders or politics. Thus, while education is a global enterprise, workforce development is largely a national initiative. As such, STEM education and workforce development have distinct, if interrelated purposes and are shaped by a complex set of national policies and global migration and economic activity. The focus of this chapter is on STEM education and workforce development in the United States in the context of global education migration and global enterprises that employ STEM graduates from US universities.

Political history of STEM education and the workforce

The need to educate and train students and workers to take up careers in fields now collectively referred to as STEM has been a long-standing concern of educators, development practitioners, analysts, and policymakers around the world. While STEM acronymically refers to Science, Technology, Engineering, and Mathematics, the meaning of STEM as a category of education, training, and occupations has evolved over time, as has the focus of related policymaking.

The STEM history as an acronym dates to circa 2001 when it was rearranged from its earlier formulation as "SMET" by the National Science Foundation (NSF), which was the successor to NSF's traditional classification, Science and Engineering (S&E). But STEM's pre-history begins shortly after the end of World War II, when science and engineering were recognized as vital to strengthening military capabilities. The destructive force of the Atomic Bomb was the most visible scientific achievement, but the second world war was fought with a vast number of scientific and technological advances, from radar and sonar to cryptography and operations management and logistics developed by the military's statistician "Whiz Kids". A new generation of military leaders and policy makers began to actively pursue an expanded role for government in scientific and technological development. This goal was immediately linked to a need to train a substantial supply of people who "understand the fundamental laws of nature and are skilled in the techniques of scientific research" (Bush, 1945; Zachary, 1999). And thus, in the mid-1950s, Congress asked the National Academies of Sciences to regularly conduct a census of the science and engineering workforce to have an ongoing assessment of the nation's science and technology capacity. Having sufficient numbers of scientists and engineers would be vital should there be another Manhattan project–which had developed the Atomic Bomb–and more generally necessary to advance the civilian and military development envisioned by the President's science adviser in the *Endless Frontier* (Bush, 1945).

From the beginning, the expansion of STEM supply was viewed as necessary not just for the military, but also for the private sector and advancing the nation's standard of living. Similarly, this period was the start of a perennial complaint that a wide range of the nation's ills—from military and economic weakness to an inability to compete with the technological prowess of, first the Soviet Union and later various Asian nations—came from the failure to produce enough graduates in mathematics, engineering and the sciences. In 1958, a five-part series in *Life* magazine compared the educational environments of two students, one in the US, the other in the Soviet Union, depicting the US school system as relatively lax and unfocused—particularly in the sciences. It appears this story was designed to raise Cold War fears, and it may not have been a faithful piece of journalism. Among a number of distortions, the Soviet student was likely a fiction of *Life* magazine (Bracey, 2009, p. 43), and the articles served to further its ultraconservative ideologue publisher Henry Luce's broader policy efforts to raise public fears about the Red Menace (Brinkley, 2010). Luce, along with other policymakers and corporate leaders, was battling President Eisenhower's efforts to reduce military spending and improve diplomatic relations with the Soviet Union. The attack on US education was part of the effort to shift US policy to confrontation with the Soviet Union by containing liberal arts education in the US that was, Luce argued, leading youth to question a hardline anti-Soviet attitude and toward liberal politics more generally (Bracey, 2009).

The most remembered, and misremembered event of the period was the successful launch of the *Sputnik* satellite in 1957 as part of the International Geophysical Year. Although the Soviet launch preceded by several months the American launch of a satellite that had a scientific mission, the political fallout lasted decades. Both nations had entered the International Geophysical Year (IGY) in 1957 with the jointly announced goal of each launching a satellite as global scientific and technological projects during IGY. The Soviets then sought the public relations coup of first-to-launch with an abbreviated scientific and technological mission. The US satellite that launched a few months later, the Jet Propulsion Lab's Explorer 1, had a cosmic ray detector that confirmed what became known as the Van Allen radiation belt. A month and a half after that, Vanguard I went into orbit to transmit upper atmosphere measurements, continuing to relay information for six years, and is still orbiting today. Sputnik was in orbit for three months and had only a beeping transmitter that sent a radio signal for a mere three weeks and provided no scientific information. Like much of STEM policy over the decades, the narrative of weakness and failure that emerged from Sputnik had little correspondence to the evidence; Soviet satellite strength was transitory and overplayed, as was its technological and economic prowess more generally. Nonetheless, the STEM myths based on fear had a more important role than evidence in shaping US policies.

In 1958, Congressional education leaders, notably Alabama's Senator Lister Hill and Representative Carl Elliot were, after a decade of failed attempts, finally able to broker a political compromise to steer federal funds into education systems. Labeled the National Defense Education Act (NDEA), thrice-defeated federal education legislation was revived and, after a year of lobbying and public campaigns such as the *Life* magazine series, these Alabama congressmen navigated a difficult legislative path providing federal funds to schools that were controlled by states and local school boards without fear of federal regulation in matters such as desegregation following the 1955 *Brown v. Board of Education* Supreme Court ruling (Urban, 2010).

The NDEA provided funding for school buildings and programs in sciences and foreign languages. It provided federal support for higher education in the form of loans and fellowships with a priority to sciences and foreign languages, though a wide range of fields were supported as long as the college would administer loyalty oaths to its students; 166 colleges, however, publicly protested the provision, with 32 turning down all NDEA funding, including Harvard, Yale and Princeton (Clowse, 1982). Although the passage of NDEA is regarded as addressing a science and engineering shortage, the legislation came on the heels of the 1957 publication of a landmark study of *The Demand and Supply of Scientific Personnel* by National Bureau of Economic Research labor economists Blank and Stigler, who found no such shortage (Blank and Stigler, 1957).

Global politics have continued to be an integral part of the narrative about the importance of STEM and proposed legislative responses. As further history shows, global threats and claimed weaknesses are perennial, never solved, and conveniently raised to advance other political goals. It was thus, two decades later following a period of economic doldrums and declines in military spending and prestige that education once again took center stage in the nation's failures. The 1983 report entitled *A Nation at Risk* identified US schools as responsible for "the educational foundations of our society presently being eroded by a rising tide of mediocrity that threatens our very future as a Nation and a people …. If an unfriendly foreign power had attempted to impose on America the mediocre educational performance that exists today, we might well have viewed it as an act of war" (National Commission on Excellence in Education, 1983). Perhaps not unintentionally, the report coincided with Reagan's highly controversial arms build-up through unprecedented peace-time deficit spending and funding for fantastical outer space technology development dubbed the "Star Wars" defense system, taking aim at the Soviet Union.

Once again, an educational failure report was followed by a serious study of the evidence that found the report's claims lacking. Most notably, the Department of Energy's Sandia Laboratories reexamination found the evidence weak and in error, and the prose hyperbolic (Carson et al., 1993). Nonetheless, the *Nation At Risk* report fueled proclamations of educational failure as the pivotal explanation for the economic declines of the previous decade (Freeman and Salzman, 2018; Weinstein, 1998) and added to the general fear of the Soviet Union.

In 2005, during the Bush administration's efforts to expand vouchers and charter schools to privatize education (Ravitch, 2020, 2014), and during a period of public doubt about the nation's military standing in the world, another commission rushed out a report that bore a title refashioned from Churchill's warning of *The Gathering Storm* about the Third Reich's ascendancy. The National Academies report, *Rising Above the Gathering Storm*, (RAGS), led by a defense contractor's retired CEO, advanced a similar argument to earlier reports—that US schools were failing in math and science relative to other countries, and that massive investment was needed in these subjects to maintain competitive advantage in an increasingly technology-driven global economy (National Academy of Sciences et al., 2007). The report's findings were echoed by numerous industry association reports and policy briefs, and provided support for Congress's passage of the America Competes Act in 2007. The Act had a broad agenda of funding science and technology research, and increasing NSF's budget, along with renewed emphasis on expanding the supply of STEM workers, especially increasing the supply of guestworkers, in response to a claimed shortage. At the same time, and once again, careful reviews of the evidence found the claimed shortages and loss of international competitiveness—to China, rather than the Soviet Union this time—was based on a flawed analysis of the data (Lynn and Salzman, 2010; Lowell and Salzman, 2007).

By 2007 when the report was issued, a booming economy made the claims of impending STEM failures less urgent than they had seemed following the dot-com crash earlier in the decade, when the crisis and failure reports began to proliferate (Teitelbaum, 2014). But a year later, the 2008 financial crisis put concerns about the US economy on center stage again.

In response to the financial crisis, an assemblage of science and industry advisers, along with many of the same authors of the 2007 RAGS report, offered in a 2010 follow-up the same argument of science and engineering declines in face of an ascendent China that portended an imminent threat to the nation like a "Category 5 hurricane." To the earlier report this one added further claims, again hyperbolic and fantastical, concluding the failure to respond to their first report could be seen as leading to outcomes that—quoting another 2001 report on which the same military contractor CEO served—were "second only to a weapon of mass destruction detonating in an American city … " (National Academies, 2010, p. 66–67).

At the same time, President Obama assigned his President's Council of Advisors on Science and Technology (PCAST) the task of examining the future STEM needs in the economy. To bolster the mission of this group of science advisers, the President assembled a group of a dozen and a half industry executives and two labor representatives in an ad hoc Council on Jobs and Competitiveness, for which he tapped General Electric's CEO Jeff Immelt as chair. Their task was to formulate policies to address the causes of, and remedies to, the economic crisis and slow recovery. Remarkably, if consistent, the solution both councils identified was to increase the number of STEM graduates: the Jobs and Competitiveness council issued an interim report in June 2011 calling for 10,000 more engineers (Presidents Council on Jobs and Competitiveness, 2012). Shortly after that, the Science and Technology Advisors, in February 2012, called for one million more STEM graduates (Presidents Council of Advisors on Science and Technology, 2012).

Both of these proposals came a year after Apple's co-founder Steve Jobs told the president that Apple would have located its vast low-cost manufacturing operation, with 700,000 jobs, in the United States instead of China if only the company had been able to find enough US engineers to support its operations. And all these reports came on the heels of Obama's proclamation a year earlier that a new "Sputnik moment" had arrived, calling for more STEM workers to lead the economic recovery. Defying the evidence of vast numbers of STEM graduates without STEM jobs, the president, policy makers, the press and industry all united in their claim of STEM shortages. The shortage claim was once again used to advance political and policy goals of refocusing attention to failures of the education system rather than the financial system, and to renew calls for increases in lower paid guestworkers for the technology industries (Teitelbaum, 2014; Lynn and Salzman, 2011; Salzman, 2013).

STEM education and workforce development garners attention distinct from overall education and workforce development. In the post-war period, the strategic importance of science and engineering came from the obvious role it had in military weaponry as well as the general increase in the role of science and technology in the economy and everyday life. However, STEM policy was encumbered from the beginning with other political and policy objectives. As the focus of attention in response to broader anxieties—whether about international threats or domestic economic crises—STEM policy is seldom based on substantial empirical analysis. In particular, the persistent theme of STEM shortages is one of unfounded claims that often arise during a general period of economic or political turmoil; each and every time major reports on the STEM crisis have been issued, they have been found not to reflect reliable evidence.

Importantly, claims about STEM education and the workforce are often made with little conceptual clarity, and little empirical evidence, yet the STEM crisis remains a potent narrative that has wide appeal and broad applications in advancing policy in education and workforce development. It seems to matter not that, in more than half a century of STEM education and workforce shortage claims, the supporting evidence has never withstood careful examination; in fact, although "STEM" is a term widely used, it has no consistent or coherent definition.

What is STEM anyway? Conceptual and definitional issues

For all the political importance ascribed to STEM, it has come to describe a rather wide range of disciplines and occupations, inconsistently used from one study or policy to another, and all lacking a logically or empirically consistent or defensible definition. Does STEM denote fields of study? Occupations? Or a body of knowledge that is applied across any number of occupations? Indeed, all of these permutations are used in discussions and policymaking about STEM. The lack of a precise and agreed-upon definition of what counts as a STEM course, major, or occupation is a problem that, we find, would alter the evidence base that is used in many policy, funding, and education decisions. As it relates to education and workforce development, STEM is both a category of education and occupation. In this regard, there are two important sources of ambiguity in the definition of STEM.

The first of these is whether to include health majors and occupations under the heading of STEM. The first census of science and engineering (S&E) was developed by NSF for a series of indicators responding to Congress's request for an assessment of the nation's scientific and technical workforce. Because another US government agency—the National Institutes of Health (NIH)—is responsible for health and medicine, these fields are generally excluded from NSF's funding and data collection efforts. But as is obvious to even casual observers of education and workforce training, this distinction is more political than substantive. The curriculum for premedical studies overlaps significantly with the laboratory sciences of biology and chemistry, and health programs outside of premed have become increasingly reliant on mastery of scientific and technological content. The decision not to include graduates in health fields has an enormous impact on the reported size of a graduating STEM cohort or the STEM workforce (Oleson et al., 2014); including health graduates in STEM would increase the size of the STEM cohort by 20% or more. However, for the purpose of this analysis we follow nearly all other analyses of the STEM workforce and exclude health fields from our accounting of STEM education or the workforce.

A second problem relates to the definition of "technology"—the T in STEM. Programs of study in Computer Science and Information Technology may fit most neatly under the "technology" umbrella, but beyond this, what constitutes a technology program of study is unclear. In a rather remarkable expansion of the definition, the STEM label has been applied to HVAC installers and automotive technicians, and perhaps even includes janitors with the title "environmental engineer" (Rothwell, 2013). But apart from these ventures into empiricist absurdism, the technology workforce as part of the STEM classification refers to those with a college degree in a recognized technology field—computer science, manufacturing technology, etc.—or those in a professional occupation classified by the Bureau of Labor Statistics as technology fields such as computer programmers. When considering those with a technology degree, four-year and post-graduate degrees considered technology include computer science and engineering, while two-year Associates degrees also include machinists, repair technicians, etc. Health technicians such as radiology and EKG technicians, could be classified in either technology or health care. We developed a specific category of Health-tech for this group and do not include them in the STEM-technology grouping.

The estimates of demand for STEM workers and their potential supply, because of the diversity of the occupations, education, skills, and disciplines subsumed by the acronym, cannot be determined with any empirical or logical consistency or reliability. Workforce, education, and policy analysis thus needs to consider the specific disciplines and occupations that are relevant for a particular policy or program.

STEM demand and supply

To understand whether the supply of new workers is adequate depends on first identifying the number and trend of available jobs in STEM—demand—and the number of available STEM workers—supply. But since there isn't a standard or consistent definition of STEM, or of the specific qualifications needed for STEM jobs, discussions of STEM in the aggregate tend toward speculation and/or serving political purposes. For example, the more broadly one defines STEM, the larger the needed labor force, and thus the larger the potential to find a "shortage," particularly—and paradoxically—when supply is not limited to a specific field of study. Estimates of the size of the STEM workforce vary dramatically based on whether these figures include healthcare occupations and "blue-collar" work involving machinery (e.g., advanced manufacturing), and on the decision whether to include jobs requiring less than a bachelor's degree (see below). One analysis found that estimates of the size of the US STEM workforce ranged from 5.4 million to over 26 million, depending on such operational choices (Oleson et al., 2014).

The largest category of US STEM workers, excluding health, is Information Technology (IT). In recent years, the IT industries have demand to fill about 50,000 new jobs per year (Zilberman and Ice, 2021) along with replacements for workers leaving these fields, with many of these jobs requiring less than a Bachelor's degree (see Fig. 1). In terms of supply, for the last eight academic years, the number of Bachelor's Degrees awarded in computer science awarded in the US has exceeded 50,000, and trended sharply upward, to over 95,000 in 2020. A similar trend of increased degree production is evident in engineering, where the number of new BAs increased from just over 75,000 in 2011 to over 129,000 in 2020. Demand for new engineers, however, is not expanding rapidly—that sector was only expected to have about 50,000 job openings per year, of which only 14,000 were new jobs and the balance replacements for retirements and those leaving the field (Torpey, 2018).

The technology industries pose a special case for estimating supply because the disciplinary background of that workforce is largely outside of computer science or IT fields, and even outside of STEM. Since nearly 30% of the IT workforce has less than a four-year college degree, and nearly half of those with a bachelor's degree did not major in computer science or engineering (see Figs. 1 and 2), the industry has a vast pool of potential workers to draw on for employment from the 470,000 STEM bachelors graduates, and 1.5 million non-STEM bachelors graduates, each year (U.S. Department of Education, 2020). The IT industry's very high turnover rates—reflecting its "burn and churn" employment practices that lead to low tenure—along with its preferences for hiring lower-cost guestworkers, may be factors that lead to the technology industry's stated demand as significantly higher than reflected in these projections (Lazonick et al., 2014; Salzman, 2016). Obviously IT occupations require a specific set of skills that may not be available in the population at large, but the rather modest needs of this industry for new hires, representing 8% of all industry annual workforce growth (Dubina et al., 2020), suggests the IT industry should be able to address its supply needs with no more difficulty than other STEM industries that require much higher levels of formal education and training (see Fig. 1).

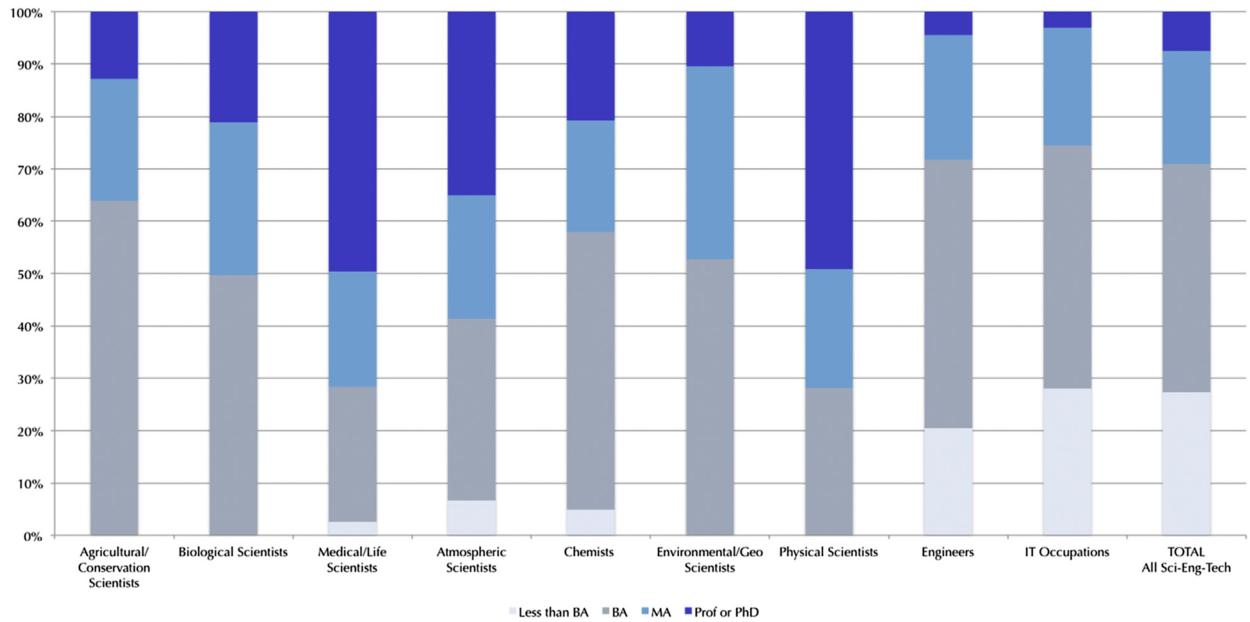

Fig. 1 STEM occupations by educational attainment. Authors' calculations based on: Steven Ruggles, Katie Genadek, Ronald Goeken, Josiah Grover, and Matthew Sobek. Integrated Public Use Microdata Series: Version 7.0 [dataset]. Minneapolis: University of Minnesota, 2017. https://doi.org/10.18128/D010.V7.0.

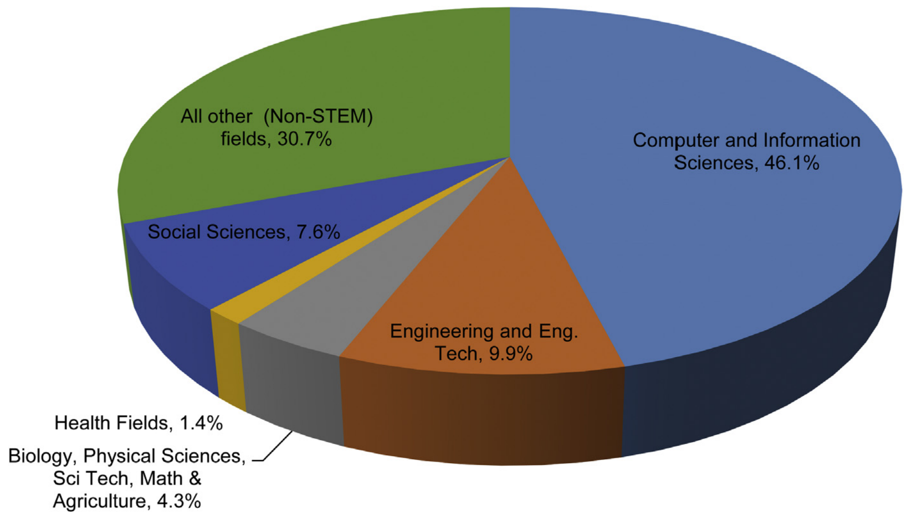

Fig. 2 IT workforce entrants' degree and field of education. Authors' tabulations based on: U.S. Department of Education, National Center for Education Statistics, Baccalaureate and Beyond Longitudinal Study (B&B), 2008/2012.

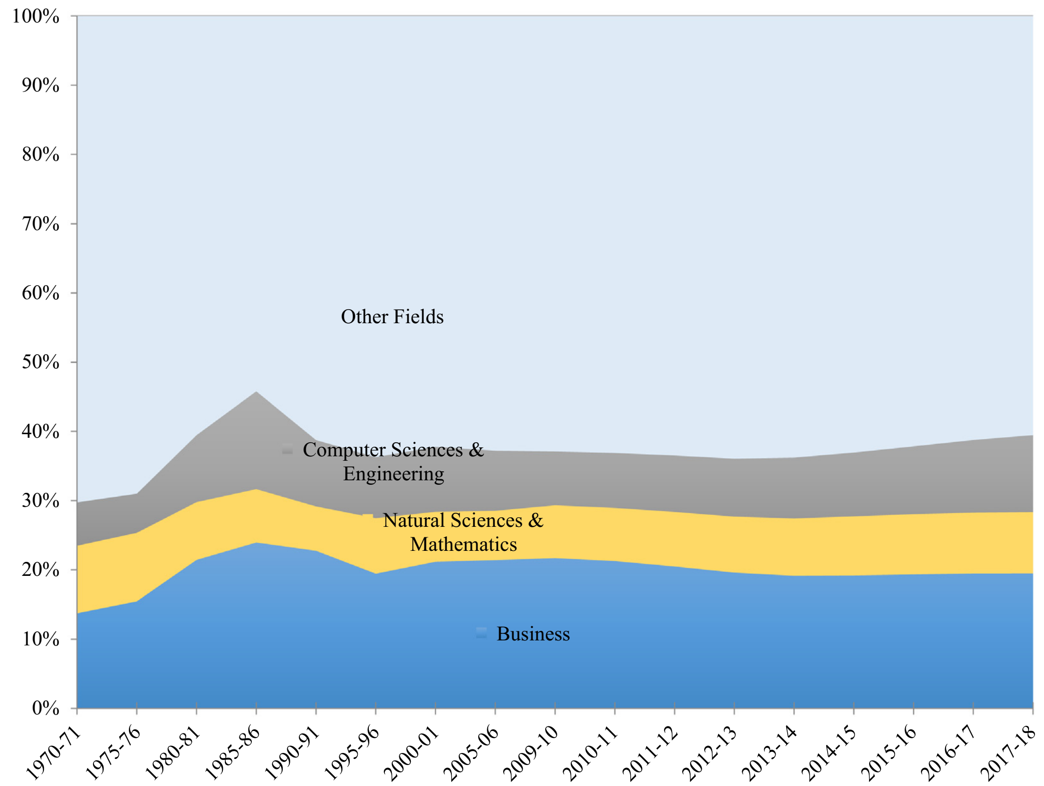

Fig. 3 Major fields of bachelor's graduates. Authors' tabulations based on: Digest of Education Statistics, 2015–2019 NCES Chapter 3.

Global STEM supply and domestic labor markets

The supply of domestic and global graduates varies quite dramatically by discipline and degree level, as do the labor markets for each occupation. Traditional calculations that examine just national education and labor markets without consideration of global flows do not accurately reflect STEM workforce supply and demand. Nor do analyses that examine these factors aggregated across disciplines or occupations provide much insight. In the US, the STEM supply and labor markets are structured to a significant degree by several guestworker policies enacted primarily for the technology industries and for computer science and engineering degrees, but also include the other STEM fields. These are guestworker work permits and visas known as the Optional Practical Training

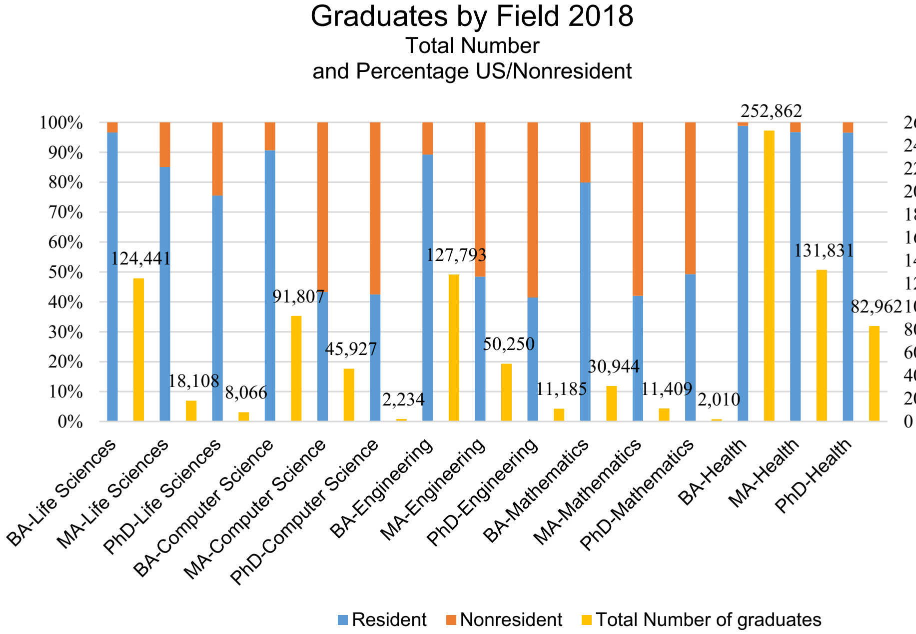

Fig. 4 Global student flows and graduate supply. Authors' tabulations based on: National Center for Education Statistics, Integrated Postsecondary Education Data System (IPEDS), 2018.

(OPT) student work permit, H-1B nonimmigrant high skill visa, and a few other categories such as the L-1 non-immigrant intra-company transfer visa. These visas are estimated to supply a guestworker labor pool equal to between one-half to two-thirds of all new entrants to the technology industries (Salzman, 2016; Rosenthal, 2021).

The supply of potential guestworkers, college graduates who qualify for a nonimmigrant visa or work permit, varies by degree level and field. As shown in Fig. 4, foreign students are a small share of bachelors graduates but comprise over half of Masters graduates in computer science, engineering and mathematics. Student flows into technology master's degree programs have increased dramatically in recent years. This reflects a change in US visa policy that vastly expanded the workforce entry options for foreign students. The two major routes into the workforce for foreign students during the 1990s and early 2000s had been the H-1B visa and, with much longer waits, permanent resident status known as the green card. Congress proposed legislation to expand these programs, in part fueled by the industry-driven shortage reports discussed earlier, but ultimately failed when the guestworker legislation was merged with broader immigration legislation (although part of the immigration bill, the H-1B visa and related visas and work authorizations, such as the OPT work authorization for the student F visa, are guest worker, nonimmigrant visas but often and erroneously described as immigration visas in the media and research reports). Consequently, to provide the technology industry greater access to guestworkers, the existing one-year work permit for all foreign graduates, known as the Optional Practical Training (OPT) work authorization, was extended to 17 months in 2008 for STEM graduates and then, in 2016, the Obama administration extended it to two years for STEM graduates, in addition to the one-year OPT for all graduates, thus creating a three-year work permit for STEM graduates (Rosenthal, 2021).

This liberalizing of the OPT work permits in 2016 led to a dramatic increase in the numbers of foreign students obtaining three-year work permits, nearly doubling from 2016 to 2019, and increasing 13-fold from 2009 (Fig. 5). As found in an analysis by Bloomberg journalist Rachel Rosenthal in a recent in-depth analysis:

> With no annual cap, the number of work authorizations exploded, to 203,000 in 2019 from 83,000 in 2008, according to Immigration and Customs Enforcement, which oversees many aspects of the program. About 411,000 people had documentation to work under OPT in 2019, not including another 126,000 from a related pre-graduation version of the program. The number of initial approvals for OPT has exceeded those for H-1B visas every year since 2015, according to data from US Citizenship and Immigration Services.
>
> Rosenthal (2021).

Since there is no cap on the number of OPT work authorizations for the F visa, and it has none of the minimal wage or work protections of the H-1B visas—thus allowing employers to hire them as low as the federal minimum wage of $7.25 per hour—these graduates became the preferred source of new entrants. Universities recognized the revenue potential of the OPT program because graduates from their two-year Masters programs could then easily enter the US labor market for three years while trying to obtain the more limited number of six-year H-1B visas. There was rapid expansion of Masters programs in computer science and engineering targeted exclusively or near exclusively to foreign students who would pay full tuition as the price of entering the US labor market.

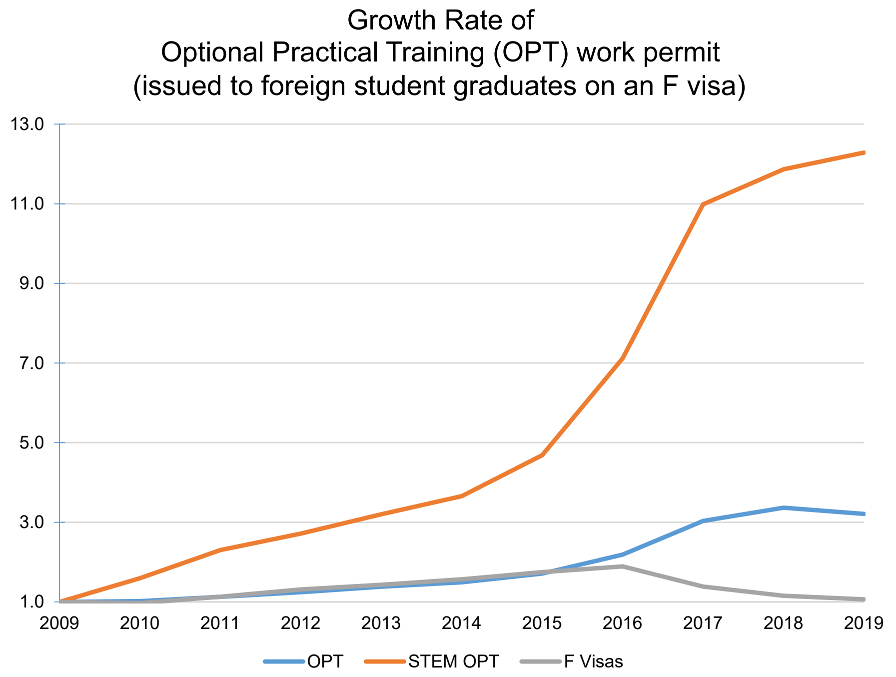

Fig. 5 Growth rate of OPT Calculations by authors; based on U.S. Immigration and Customs Enforcement SEVIS data 2008=1.0/F visa, OPT; 2009=1.0/OPT STEM; OPT STEM lagged 1 year—Issued at expiration of first year OPT.

Although some colleges with established and reputable programs created or expanded their Masters programs for foreign students, the vast majority of graduate supply in technology fields came from unranked and low-ranked programs: "More than 70% of nonresident computer science master's degrees awarded in 2018 came from unranked programs or those ranked 50 and lower by US News and World Report. Just 17% came from schools ranked in the top 25" (Rosenthal, 2021). In the past decade the colleges with the largest cohorts of Computer Science graduates were the unranked universities of Wilmington University, Central Missouri State University, Southern Arkansas University, and University of Cumberlands, where over 90% of the graduates were nonresident, or foreign students. Overall, more than two-thirds of nonresident computer science Masters graduates were in programs that could be considered exclusionary, that were 75%–100% nonresident students. This level of exclusionary programs is specific to Masters and PhD programs in computer science, some fields of engineering, and mathematics (see Fig. 4).

It was in this way that legislation provided the technology industry the opportunity to hire guestworkers at below market wages (Hira and Costa, 2021) which, in turn, shifted the demand away from domestic to nonresident foreign computer science and engineering graduates. In response, some universities shifted their business model to create programs that exclusively, or near-exclusively recruited full-tuition-paying nonresident foreign students. Justifying the expansion of these programs, with a large share coming from universities without a history or evident credentials in these fields, the STEM shortage narrative provided justification for the policies that sustained these programs (Rosenthal, 2021; Salzman, 2016). It is, thus, the intersection of government policies, global labor supplies and the opportunity for global labor arbitrage, along with entrepreneurial initiative by some universities that combine to structure one segment of the technology labor market different from other STEM labor markets or STEM education.

In summary, the evidence does not support the longstanding narratives of STEM shortages or the predictions of dramatic increases in demand that cannot be met by existing education institutions to provide the necessary supply (Salzman and Benderly, 2019; Lynn et al., 2018). Considering the political and industry functions of the STEM shortage narrative, and the development of a technology student and worker supply system that is exclusionary and draws on neither the high-talent capacity nor the potential diverse domestic pool of students and workers, the evidence suggests that the global education and employment systems inhibit full development of the STEM workforce potential in the nation.

Problems and problematics in the supply

Up to this point, we have raised questions about the definition of STEM and assessed claims of shortages of college-educated STEM workers. But beyond the issue of relative levels of supply and demand, there is of course a need for a trained or re-trained STEM workforce at both the Baccalaureate and sub-Baccalaureate level. It is thus necessary to assess obstacles to producing that supply of workers at both levels. This is particularly important when considering factors that can facilitate or hinder the development of a diverse STEM workforce and of drawing on the full potential within the nation's population.

Sub-baccalaureate STEM credentials

While most discussions of STEM workforce development emphasize the supply of bachelor's degree graduates, it is important to recognize that over a quarter of all STEM occupations require less than a bachelor's degree (**Fig. 1**). Furthermore, nearly half of students who ultimately earn a bachelor's degree in the US spend at least some time at two-year postsecondary institutions, community colleges (NSC Research Center, 2017). And as concerns about diversity in the STEM labor force grow, it is important to consider that community colleges serve a more diverse population of students than any other sector of postsecondary education, and at much lower cost, providing greater access to lower-income students. Community colleges are thus a critical part of the STEM worker supply in the US (National Academy of Engineering and National Research Council, 2012), and any consideration of the STEM workforce needs to consider the role played by these two-year institutions.

Although community colleges are more diverse and provide greater access to education than four-year colleges, the completion rates are less than a third of those in four-year colleges. One study of students in the midwestern state of Ohio found that among students who begin their college careers at two-year institutions with intention to pursue a STEM major, only 14% remained in these fields at the time of their last enrollment, as compared to 43% of four-year college students (Bettinger, 2010). More recent figures indicate that 69% of entering STEM students at two-year colleges had either switched majors or left college altogether (Chen, 2013). Importantly, attrition rates from STEM fields are not dissimilar from non-STEM fields (Chen, 2013). But the difference in attrition rates between two- and four-year programs suggests that there may be differing supply problems in these two sectors.

Mathematics coursework and the supply of STEM graduates

Attrition from STEM majors is exacerbated by a curriculum structured to filter out students through mathematics courses that are not always necessary for the major. These are known as gateway courses because they can be a barrier to entry or continuation in a STEM pathway. At both the baccalaureate and sub-baccalaureate levels, entry or advancement in STEM fields of study is often contingent upon completion of mathematics courses. Indeed, such "service courses" for other fields of study are the primary function of mathematics departments in US colleges and universities. Our analyses of college transcripts indicate that STEM bachelor's degree earners completed about 17 mathematics credits—the equivalent of about five courses—compared to 8 credits among non-STEM majors. Among non-mathematics STEM majors, students in engineering (22 credits), physics (17 credits) and computer science (16 credits) earned the most math credits, with life sciences majors earning the fewest (9 credits). Notably, courses in college-level math and calculus in US colleges have uniquely high rates of failure and withdrawal, at 10% each, even when compared to other STEM courses (ranging from 3–5%), suggesting that mathematics courses play a gatekeeper role in STEM fields (Douglas and Salzman, 2020).

Mathematics remedial courses serve an additional gatekeeper role at the sub-baccalaureate level. Early in the last decade, nearly 60% of entering US community college students were assessed as needing remedial instruction in mathematics; almost double the one-third of students needing remedial instructions at baccalaureate institutions (Chen and Simone, 2016). Remedial placement decisions are typically made on the basis of one-off standardized tests, even as rates of misplacement with such tests were found to be fairly high (Scott-Clayton et al., 2014). Rather than remediating identified mathematics deficits, these courses lead to a high rate of students leaving without completing any degree (Attewell et al., 2006; Chen and Simone, 2016). Indeed, the pre-college level mathematics courses have the lowest success rates of any course type in US postsecondary education; nationally representative student transcript data shows that only 57% of pre-college mathematics course attempts end in success—grades of C or better—compared to 79% of college physics courses and 77% of college English courses (Douglas and Salzman, 2020).

Colleges, especially community colleges where the problem is most severe, have recognized this issue, and have begun to respond. Reforms to remedial mathematics policy have ranged from reforming curriculum and pedagogy to altering placement mechanisms, to modifying remediation requirements or eliminating them altogether (Rutschow et al., 2019). One element of curricular reform is to align required mathematics content with students' intended fields of study, based on the assumption that different degrees will require different types of mathematical knowledge. Generally, this has meant that students intending to pursue non-STEM degrees are placed on a track to take introductory statistics or other non-algebra courses, while STEM-intending students are placed on a track to take college algebra and/or calculus. In general, these reforms have succeeded in reducing rates of remedial mathematics placement and increasing college completion (Center for the Study of Social Policy, 2016). The gatekeeper function of mathematics courses, to "weed out" and reduce the pool of STEM-eligible students, is a longstanding practice but is not grounded in evidence for its utility pedagogically or occupationally. Research on mathematics use among US workers indicates that a very small proportion of US workers—even those in occupations that require college degrees—make regular use of mathematics beyond simple computation (Douglas and Attewell, 2017; Handel, 2016). Alignment of mathematics requirements with students' college-level coursework and eventual occupations needs to be carefully considered, especially if mathematics coursework requirements are limiting supply by increasing attrition from STEM majors or college dropout altogether.

STEM attrition and STEM attraction

The traditional—and often unexamined—narrative of STEM education in US higher education is the so-called "leaky pipeline." This narrative and supporting analyses are based on the observation that many students who begin their postsecondary education career in STEM fields change to non-STEM fields of study and ultimately graduate with a non-STEM degree. This pattern of STEM attrition has been the subject of many studies, with particular focus given to the departure of female and underrepresented minority students

(Seymour and Hewitt, 1997; Crisp et al., 2009; Hill et al., 2010; Chen, 2013). Consequently, policymakers in the US have focused attention on retention, of plugging leaks in the pipeline by creating programs to retain students in STEM majors.

The focus on retention is a positive development to the extent that it spurs cultural changes in STEM fields, such as reducing discrimination against particular groups of students or improving pedagogy. However, it is also important to recognize that college is a process of discovery about interests and abilities, and some amount of change in field should be expected and is beneficial. Indeed, nationally representative survey data indicate that one-third of four-year college students change their major at least once within their first three years, and that students leaving STEM majors is about as common as students leaving non-STEM majors (Leu, 2017). The focus on STEM education as a "pipeline" that has only unidirectional "leaks" has led to a truncated analysis that fails to consider the "late entrants" who discover and move into a STEM field after their first years following an initial period of exploration.

In our analysis of this flow of students from college entry to graduation, we find that although a large share of four-year college freshmen leave STEM majors and switch to non-STEM majors, there is a slightly larger number of students who begin as non-STEM or as undeclared majors and are "late entrants" into STEM (Salzman et al., 2021). This results in the graduating STEM cohort becoming larger than the starting STEM cohort. The assumption that STEM completion is predicated on initial entry into STEM is thus not supported by this evidence, nor by an assessment of the "STEM-potential" of the non-STEM student population.

The large pool of non-STEM students who are STEM-potential is indicated by the significant share of students with high levels of mathematics coursetaking: there are twice as many non-STEM college majors as STEM majors with mathematics course credit levels at the STEM population median level of mathematics course credits (Douglas and Salzman, 2020). That is, the non-STEM population is large and a significant share of them take mathematics at the same level of intensity as half of the STEM population. Some fields such as engineering are more difficult to enter late, but the vast majority of STEM fields do not require, nor does the typical major have STEM course intensity that is beyond the capacity of late entrants.

Moreover, if fostering flows in and out of STEM results in better matching, it may lead to better performance, satisfaction, and tenure in STEM careers. Currently, only a quarter to a third of STEM-degree holders work in a STEM occupation, and 15% of those in a STEM occupation with a four-year degree do not have any STEM degree (Kannankutty, 2007; Landivar, 2013). Instead of trying to "plug the leaks," or making the boundary less permeable, a more productive approach might be analysis of STEM attraction rather than of just attrition, focusing instead on ways to improve the exploration and matching processes of students, of understanding both factors that account for retention/persistence *and* the factors that attract students into STEM fields.

Finally, we may want to reconsider the assumption that STEM development and national competitiveness are best served by strengthening a pipeline that has high throughput with minimal flows across disciplinary boundaries. For the STEM-eligible population, of the pool of high-performing students, it may be the loose coupling between STEM disciplines and STEM careers that provides the US some of its dynamism, innovativeness, and creativity. Steve Jobs famously said that Apple, among the world's most highly valued companies, represents the intersection between technology and the humanities. Before Jobs, Edwin Land, co-founder of Polaroid and a developer of the nation's first advanced aerial imaging technology as well as key advisor in the founding of NASA, had discussed the importance of "standing at the intersection of humanities and science." The porous boundaries of the US education and career system should be seen as a strength that supports and fosters the creativity of cross-disciplinary meandering.

Conclusion

Simple notions about STEM workforce policy fuel debates about national competitiveness the world over. In the United States, the STEM crisis theme is a perennial policy favorite, appearing every few years as an urgent concern in the nation's competition with whatever other nation is ascendant, or as the cause of whatever problem is ailing the domestic economy. And the solution is always the same: increase the supply of STEM workers through expanding STEM education. Time and again, serious and empirically grounded studies find little evidence of any systemic failures or an inability of market responses to address whatever supply is required to meet workforce needs. The large share of the STEM workforce that requires advanced college degrees means that supply responses will be lagged by two or three years, but in decades of study there is no evidence of a failure to create whatever supply employers are seeking to hire at market rates (Freeman, 1976; Salzman, 2013; Lynn et al., 2018; Freeman and Salzman, 2018). Instead, the motivating interests of STEM workforce shortages or failures are found to be attempts to shape policies for other goals, most recently to lower the cost of labor through global labor arbitrage facilitated by policies responding to manufactured crises (Berliner and Biddle, 1997; Teitelbaum, 2014).

Although the goal of increasing support of STEM education and workforce development would seem to benefit from this increased attention and funding, even if the motivation is misguided, the seemingly paradoxical effect of these policies is to undermine the nation's, and the world's STEM workforce development and capacity for innovation. The expansion of guestworker policies and programs has created a shadow STEM workforce system of universities that create Masters programs to supply the lower cost, guestworker labor market (Hira and Costa, 2021; Rosenthal, 2021; Salzman, 2016), and that allows employers to pay below market wages—in the case of H-1B workers, transferring $3 billion to $4 billion per year of forgone wages from employees to employers (Employment and Training Administration, 2021). This global labor arbitrage system leads firms to disinvest in their STEM workforces and rely, instead, on a low-cost, high-churn model of employment (Lazonick et al., 2014). To the extent that the quality of the STEM workforce is a factor in endogenous growth models explaining national economic performance, this STEM disinvestment might be contributing to the recent productivity and innovation declines (Gordon, 2016).

STEM education and workforce development have suffered in the wake of policies purported to be strengthening them. Education and workforce policy are part of the overall political process that reflects conflicting goals and are too often supported by analyses and policy reports that are narrowly focused without the necessary historical context or detailed empirical specificity required to develop effective policy. A broader perspective on the political context of STEM crisis reports, and more rigorous research and analyses will better inform our understanding of the STEM fields and how to best strengthen them.

Acknowledgments

This material is based upon work supported by the Alfred P. Sloan Foundation, Grant Nos. 2012-6-13 and G-2016-7310; and the National Science Foundation, Grant No. NSF-DGE-1561687. The authors are most grateful for the expert research assistance of Daniyal Rahim and Khudodod Khudododov.

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STEM Pathways Research, https://go.rutgers.edu/STEMRU.