RESEARCH REPORT

Registered Apprenticeship in Science and Engineering

Daniel Kuehn *Ian Hecker* *Alphonse Simon*

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Contents

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Introduction

Science, technology, engineering, and mathematics (STEM) education in the US is dominated by traditional brick-and-mortar college and university degree programs. But college degree programs are only one way to deliver STEM skills. An alternative is to invest in the science and engineering workforce through high-quality, structured work-based learning, such as registered apprenticeship. Registered apprenticeship is typically associated with the building trades in the US, but for centuries apprenticeship has been central to advancing the frontiers of knowledge and technology (de la Croix, Doepke, and Mokyr 2018; Meisenzahl and Mokyr 2011). Apprenticeship can be an effective model for teaching STEM skills in the modern economy; European engineers and technicians are frequently trained in apprenticeship programs. The primary obstacles to expanding STEM apprenticeship in the US are the inertia of traditional college-based STEM education and the failure to sell the apprenticeship model at sufficient scale outside traditional fields.

This report presents an overview of the current state of STEM apprenticeships in the US and draws insights from the experiences and decisionmaking processes of program sponsors. Since STEM jobs differ from jobs in other apprenticeable occupations, STEM apprenticeship programs will and should be organized differently. By sharing the experiences of current STEM apprenticeship program sponsors and articulating their program design choices, this report provides guidance to prospective sponsors and to policymakers.

The report begins with an introduction to the registered apprenticeship system, an overview of why apprenticeship is appropriate to STEM, and a review of our data sources. We draw on federal administrative data on registered apprentice and interviews with STEM apprenticeship program sponsors and related technical instruction (RTI) providers. After the introduction, we describe the characteristics of STEM apprentices, including demographics, program outcomes, and registration trends. This is followed by a discussion of the current state and organization of STEM programs and RTI providers. We conclude with a review of the challenges and successes of these programs to date, along with some recommendations.

Our analysis of existing STEM apprenticeships identifies several important features of current programs:

- Most STEM apprentices are concentrated in engineering technician programs, although our interviews with program sponsors indicated recent substantial recent growth in information technology apprenticeships.

- Although there are both racial and gender disparities in STEM apprenticeship, the gender disparities are particularly stark.
- STEM apprentices are better paid and have higher completion rates than non-STEM apprentices. Of the STEM apprenticeship occupations, engineers are the highest paid ($23.15 average exit wages), and information technology workers are the lowest ($18.52 average exit wages).
- Despite recent emphasis on the promise of group training models and intermediaries, STEM apprentices are much more likely to be registered with independent programs (programs associated with one employer rather than multiple employers) than non-STEM apprentices.
- STEM apprenticeship program sponsors express interest in competency-based training models, but use of competency-based models in STEM apprenticeship is rare (3.9 percent of apprentices are trained in competency based or hybrid programs that use a combination of clock hours and competencies).
- Most STEM apprentice programs are operated by sponsors who also operate non-STEM programs (57.4 percent).
- Only one-third of STEM apprentices get their classroom based RTI from colleges. RTI provision is complicated, and often involves mixing instruction from multiple sources.

What Is Registered Apprenticeship?

The term "apprenticeship" is used to describe a variety of related approaches to learning, so it is important to clarify what is being considered here and what makes "registered apprenticeship" distinct from other approaches used by STEM educators. The most distinctive feature of apprenticeship training is that the apprentice gets extensive paid experience as an employee on a job site, rather than an abbreviated or simulated experience such as the software engineering apprenticeship described by Surendran et al. (2002), a summer science apprenticeship camp (Barab and Hay 2001; Bell et al. 2003; Polman and Miller 2010), or a "research apprenticeship" (Feldman et al. 2013; Sadler et al. 2010). In apprenticeship, the employment relation defines the apprentice, rather than being an incidental strategy for effective learning. Apprenticeships can be registered or unregistered. A "registered apprenticeship" program is reviewed, approved, and overseen either by the federal Office of Apprenticeship or a state apprenticeship agency. This report focuses on registered apprenticeships, which often share many characteristics with unregistered programs.

A registered apprentice is paid and productively employed with an employer "sponsor" for a term of at least one, and frequently several, years. One sponsor may operate multiple programs in different occupations. Apprentices receive structured on-the-job training from skilled workers who are also employed by the sponsor and RTI, which is typically delivered in a classroom setting. Bailey, Hughes, and Moore (2004) argue that this combination of on-the-job and classroom-based learning is the most effective approach to a successful work-based learning program.

In the United States, apprenticeship is typically associated with the building trades (such as electricians and plumbers), with wide usage in certain manufacturing occupations as well. This is beginning to change, as the US Department of Labor and the private sector have tried to expand the training model into new occupations, including health care, advanced manufacturing, services, and information technology, or IT (Kuehn 2019; Lerman et al. 2008; Lerman, Eyster and Kuehn 2014).

Why Apprenticeships in STEM?

Although apprenticeship has not been common in STEM occupations in the US, the apprenticeship training model is a natural fit for these jobs. Work-based learning is already a core part of the training of engineers and engineering technicians, who are often required to participate in intensive co-op and internship programs before earning a bachelor's degree. Natural scientists' thesis research and postdoctoral experiences are all versions of paid work-based learning that complements classroom instruction. At all levels of education, from K–12 to graduate school, laboratory components of science and engineering classes highlight the importance of hands-on task completion for STEM pedagogy. Kuehn and Hecker (2018) show that continued on-the-job training by STEM employers is already common and provides an important—although informal—link between a worker's job and their education. STEM apprenticeships would formalize and strengthen these existing links between education, paid work, and on-the-job training. One of the apprenticeship program sponsors we interviewed for this report highlighted the theory-to-practice model of apprenticeship as one of its major strengths. He noted that the STEM apprentices "can ingest theory and take it immediately to practice."

Apprenticeships are particularly important for training STEM workers in positions where troubleshooting and maintenance are important tasks, such as IT occupations and engineering technicians. However, troubleshooting and maintenance can be difficult to teach in a classroom setting. Tacit knowledge developed on the job while investigating a problem is often more effective at teaching these skills.

Skeptics of the applicability of apprenticeship to the STEM workforce must confront why other advanced market economies have been successful in using apprenticeship to invest in science and engineering skills. STEM apprenticeship in the UK is more advanced than in the US, although it has emerged in response to many of the same middle-skill technical workforce needs that are apparent in the US. Lewis's (2013; 2016) studies of the technician workforce in the UK chemical and biotechnology industries find that STEM apprenticeships were developed to cover work that was too routine for the doctoral level chemists and biologists but required additional on-the-job training. In the UK cell therapy industry, Lewis (2017) identifies employer size as a major obstacle to expanding cell therapy apprenticeships. Small employers in the need access to a skilled workforce, but often aren't operating at a scale that can support training their own apprentices. This constraint may be relevant in the US as well. Lewis (2012) finds that in the UK's space industry, technician apprenticeships help to plan for the transition of an aging workforce, which is also an explicit goal of the aerospace apprenticeships developed in Washington state (Washington State Apprenticeship and Training Council 2017).

Data Sources

This report relies on two data sources: administrative data on all registered apprenticeship programs in the 33 states that report data to the federal government and interviews conducted with STEM apprenticeship sponsors and RTI providers. The administrative data we use come from the Registered Apprenticeship Partners Information Data System (RAPIDS). These data provide information on the prevalence and characteristics of STEM apprenticeships, details program organization, and individual apprentice outcomes like completion and exit wages. The interviews provide richer context on the organization and design of STEM programs, important partnerships, recruitment, and registration processes.

RAPIDS is the federally operated information management system for the 25 states where registered apprenticeship is managed by the Office of Apprenticeship, as well as eight additional states where registered apprenticeship is managed by a State Apprenticeship Agency that uses RAPIDS for their data management activities. These states represent 72.8 percent of the total population of the US, so although the data do not cover the entire country, they include a substantial share of all registered apprentices.[1] The RAPIDS database includes over 1.5 million registered apprentices and over 50,000 registered apprentice sponsors from 1999 to 2016.[2] RAPIDS is a relational database with separate files for apprentices, sponsors, and RTI providers. The apprentice file includes detailed demographic characteristics, educational attainment, wages, and apprenticeship registration histories. The apprenticeship file also has information on the program itself, including the duration of on-the-job training and RTI, and whether the program is competency based or time based.

In addition to using the RAPIDS administrative data, we conducted interviews with STEM apprenticeship program sponsors and RTI providers drawn from RAPIDS. We sent interview requests to the largest sponsors and RTI providers to obtain information that was relevant to the greatest number of STEM apprentices. Interviewees represented a number of industries, including health insurance, precision manufacturing, utilities, shipyards and fleet readiness, and corrections. RTI providers included community colleges and private training companies.

We were able to interview representatives from 20 organizations (15 program sponsors and 5 RTI providers). The interviews were semistructured; we used standard interview protocol, but many of the questions were open-ended, generating interviews that varied in content and probed different leads from the interviewees. We began by asking respondents about their role and history with the program, then moved to questions about any apprenticeship programs outside of STEM occupations that the sponsor operated. If the sponsor also operated non-STEM programs, we discussed the relative content and difficulty of their STEM and non-STEM occupations. We ascertained the structure of the apprenticeship, which includes program types, duration of training, and the RTI provider used. Interviewees discussed benefits and challenges of the apprenticeship model both in and out of, as well as how the RTI and on-the-job training (OJT) were designed, what its current form is, and the extent to which the two are integrated. The last few interview questions asked about any challenges to establishing apprenticeship programs in the STEM fields, recruitment tactics, prerequisites, retention, and attrition.

Data from these interviews are obviously limited in that they are not representative of all STEM apprentices in the US. Although we sought out larger, more established programs, ultimately only a subset of these programs agreed to be interviewed. Respondents were generally candid, but they may have also tried to put a positive spin on their programs. These limitations are important to consider when interpreting the interview data. However, the interviews also provide rich institutional details that are not captured in the RAPIDS data. We learned about the advantages and difficulties of working with RTI providers, and about informal partnerships between different sponsors. Sponsors and RTI providers shared their considerations and processes for developing STEM apprenticeship programs. These insights are useful for strategizing how to scale STEM apprenticeship in the future.

Who Are STEM Apprentices?

It is relatively easy for most workforce development professionals to picture an apprentice working in a classic apprenticeable occupation, such as an electrician or a plumber. STEM apprentices are less familiar, and the landscape of STEM is constantly changing as standards are written for new occupations. This section reviews the types of registered STEM apprentices in the US, their characteristics, and the scale of STEM apprenticeship.

STEM Apprentice Occupations

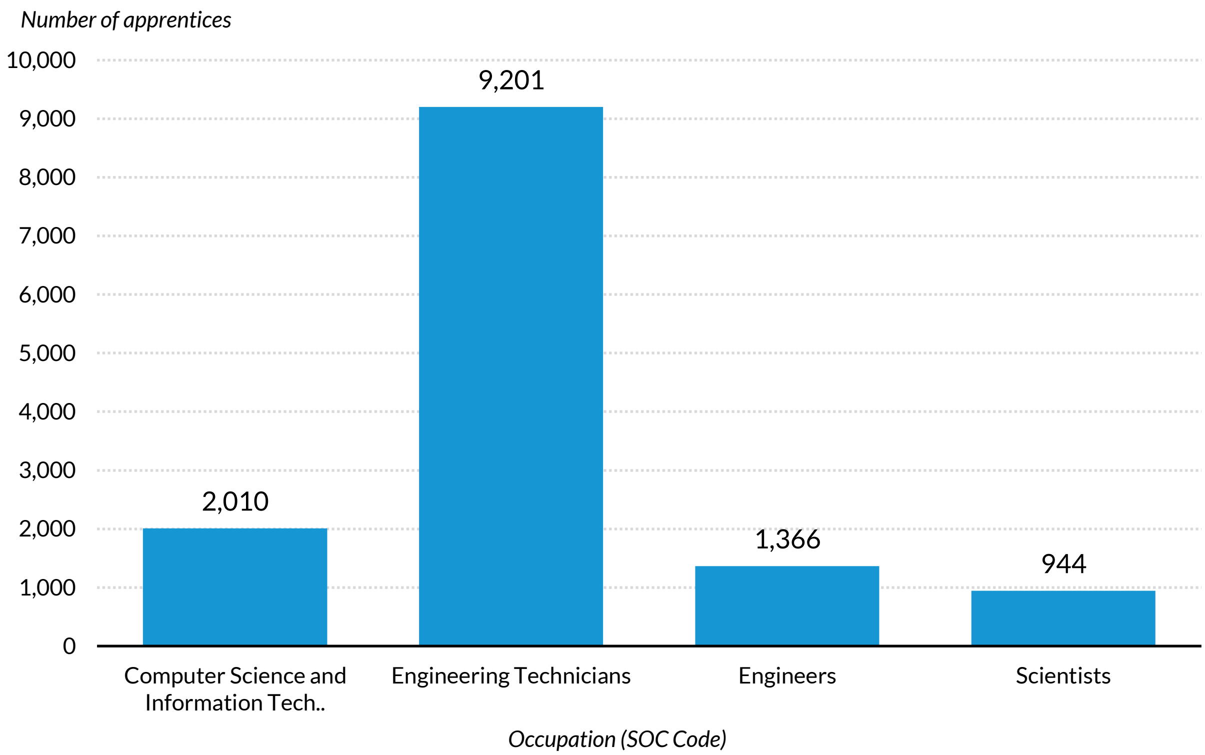
In this report, we divide STEM apprentices into four broad occupational categories based on the federal government's Standard Occupational Classification (SOC) codes. Every registered program is associated with very detailed occupational codes used in the apprenticeship system as well as a SOC code. We use the SOC codes instead of the registered apprenticeship system codes because the SOC codes are hierarchical—so they can be aggregated up to broader categories—and because they are more widely used in research. Our STEM occupation classifications are as follows:

1. Computer Science and Information Technology Occupations (SOC 15-1)
2. Engineering Technology Occupations (SOC 17-3)
3. Engineering Occupations (SOC 17-2)
4. Science and Science Technicians (SOC 19-1, 19-2, and 19-4)

Kuehn and Jones's (2018) study of sub-baccalaureate STEM education and apprenticeships also add health occupations, technicians, and mechanics. All of these require high-level technical skills but are not typically classified as STEM. We exclude these groups to focus on core STEM workers. The total number of apprentices registered in each of these four broad occupational categories is reported in figure 1.

FIGURE 1

Registered Apprentices in STEM Occupations, 1999–2016



Source: Authors' calculations from the Registered Apprenticeship Partners Information Data System.
Notes: The table excludes a small percentage of registered apprentices with missing occupational information.

Computer Science and Information Technology

Between 1999 and 2016, computer science and information technology programs registered 2,010 apprentices. Although IT has been the focus of recent efforts to scale apprenticeship in nontraditional occupations, it has generated a relatively modest number of apprentices. Apprenticeable computer science and information technology occupations range from computer programmers and network technicians to cybersecurity specialists. Sponsors are not restricted to the information technology industry—major sponsors are also operating in insurance, manufacturing, and even correctional facilities.

Community colleges are common RTI providers for computer science and information technology apprenticeships because they already have robust computer science programs that are well connected to industry recognized credentials. We interviewed one RTI provider that specialized in IT programs and offered RTI for nontechnical roles such as project management and quality assurance in technology companies described as "adjacent to software development."

Engineering Technicians

Engineering technicians are by far the most common STEM occupation. Between 1999 and 2016 there were 9,210 registered engineering technician apprentices—more than all other types of STEM apprentices combined. Engineering technicians are concentrated in the manufacturing sector, where they install and maintain equipment. Many technician occupations mirror their engineering counterparts. Just as there are electrical engineers and civil engineers, there are electrical engineering technicians and civil engineering technicians. Electrical and instrumentation technicians, die designers, nondestructive testing technicians, and quality assurance technicians are other well represented occupations in registered apprenticeship programs.

Engineering technician apprenticeship programs have recently been featured in a comprehensive book on engineering technician and technologist education by the National Academy of Engineering (2017). The book discusses registered and unregistered technician apprenticeship programs, as well as the wide variety of other work-based learning such as internships, co-ops, and on-the-job training.

Engineers

Although there are a larger number of engineering technicians nationally, engineers are not as well represented in registered apprenticeship. Between 1996 and 2016 there were 1,366 apprentices in engineering. A large majority of these apprentices were mine safety engineers registered with a program sponsored by the Mine Safety and Health Administration. Mine safety engineering has long been recognized as a subfield of engineering, but it is noteworthy that apprenticeships in classic engineering fields like electrical or mechanical engineering are nonexistent in the US. There is no reason why the apprenticeship model cannot be a significant source of education and training for engineering. European countries frequently train engineers through apprenticeships and the highest-quality engineering programs in four-year colleges incorporate substantial work-based learning through required co-ops. Nevertheless, training engineers through apprenticeship faces considerable resistance in the US. One of the RTI providers interviewed for this study suggested that it was “improbable” that their engineering programs would ever be apprenticeships, even though they already operated technician, IT, and other STEM apprenticeship programs.

Other interview subjects were more optimistic about what apprenticeship training could do for engineers. One community college that sponsored an engineering technician apprenticeship program shared how local employers would send their new engineering graduates to the program for work-based learning (though not to register in the apprenticeship), because they had no hands on experience with the equipment they would be using.

Scientists and Science Technicians

Between 1999 and 2016, there were 944 registered scientist and science technician apprentices. Most of them were registered as horticulturalists, and many were registered in prison-based apprenticeship programs. Less common occupations include chemical operators and environmental technicians.

Demographic and Other Characteristics

Registered apprenticeship in the United States has a long history of struggles with gender and racial disparities, both of which are ultimately rooted in a broader history of labor market discrimination and the male domination of traditional apprenticeable trades (Berik, Bilginsoy, and Williams 2011; Inanc, Needels, and Berk 2017; Kuehn 2017; Marshall and Briggs 1967). Today people of color are much better represent in apprenticeship, but women remain significantly underrepresented. Expanding registered apprenticeship into STEM occupations offers an opportunity to reverse these disparities. STEM apprenticeships are more racially and ethnically diverse than the same STEM occupations nationally. In contrast, gender disparities remain substantial. We consider gender disparities in STEM apprenticeships first and then explore racial and ethnic disparities.[3]

Between 2000 and 2016, less than 10 percent of STEM apprentices were women (table 1), even though women constituted one-half of the population and 47 percent of the workforce.[4] Moreover, there has been no long-term trend towards parity. Although women's participation in STEM apprenticeship is low, it is higher than the share of women in non-STEM apprenticeships between 2000 and 2016 (6.8 percent). Of the STEM apprentices that registered in 2016 alone, 12.6 percent were women. This is higher than the average for the full period of study from 2000 to 2016 and higher than the 8 percent of new apprentices who were women in the UK in 2016 (Morse 2018).

One of the RTI providers we interviewed shared that they faced Title IX complaints regarding their STEM apprenticeship programs because of low participation of women. The college took steps to remedy the issue by launching a marketing campaign in local high schools to promote the program to a broader audience.

Women in male-dominated apprenticeships confront pressures and stereotypes that hinder their capacity to advance through and complete their training. In their study of gender and STEM apprenticeships in Switzerland, Makarova, Aeschlimann, and Herzog (2016) identified four characteristics in how women cope with pressures of male dominated professional spaces. Most commonly, women in STEM apprenticeships were resilient in the face of gender disparities. They also assimilated to the male-dominated environment, demonstrated excellence to in response to performance pressure, and exhibited avoidance of especially burdensome situations.

TABLE 1

Gender of STEM and non-STEM Apprentices, 2000–2016

Apprentices in the Registered Apprenticeship Partners Information Data System

Gender	STEM	Non-STEM
Men	90.3%	91.9%
Women	9.7%	6.8%
Unknown or missing	0.0%	1.3%
Total apprentices	13,521	1,511,042

Source: Authors' calculations from the Registered Apprenticeship Partners Information Data System.

Notes: The table excludes a small percentage of registered apprentices with missing occupational information. The variable labeled "gender" in the RAPIDS database provides three response, "male," "female," and "unknown." Male and female have been changed to "men" and "women" to reflect gender categories. Missing gender has been added to "unknown." The RAPIDS data do not provide the opportunity to identify non-binary genders or gender non-conforming individuals separately, or to determine how these individuals are classified in the data.

Efforts to address gender disparities in registered apprenticeship have focused on registering more programs in occupations that are less male-dominated than the building trades and on making these occupations more inclusive of women. Both strategies have proven successful (Kuehn 2017; Mastracci 2005) but registering programs in less-male-dominated occupations has worked at a scale that has not been matched by the harder and more essential work of making male-dominated occupations more inclusive.

Racial and ethnic disparities in STEM apprenticeships are less pronounced than gender disparities (table 2). The non-Hispanic white share is higher than that of non-STEM apprentices—68.8 percent compared to 62.7 percent— and higher than the general population share of 60.6 percent.[5] The non-Hispanic black percentage of STEM apprentices is somewhat higher compared to non-STEM apprentices. However, the Hispanic share of STEM apprentices is less than one-half the share of non-STEM apprentices (8.3 percent compared to 16.8 percent). This disparity reflects the high representation of Hispanic people in the building trades, which dominate non-STEM apprenticeships. Non-Hispanic Asian, Native American and Alaska Native, and Hawaiian-Pacific Islander apprentices are better represented in STEM apprenticeship programs than they are in non-STEM apprenticeship programs.

TABLE 2

Race and Ethnicity of STEM and non-STEM Apprentices, 2000–2016

Apprentices in the Registered Apprenticeship Partners Information Data System

Race/Ethnicity	STEM	Non-STEM
White (non-Hispanic)	68.8%	62.7%
Black (non-Hispanic)	12.8%	11.8%
Hispanic	8.3%	16.8%
Asian (non-Hispanic)	2.0%	1.3%
Native American or Alaska Native (non-Hispanic)	1.8%	1.4%
Hawaiian-Pacific Islander (non-Hispanic)	1.5%	1.1%
Unknown or Missing	4.6%	5.1%
Total apprentices	13,521	1,511,042

Source: Authors' calculations from the Registered Apprenticeship Partners Information Data System.
Note: The table excludes a small percentage of registered apprentices with missing occupational information.

Unsurprisingly, STEM apprentices have higher educational attainment at registration than non-STEM apprentices (table 3). One-fifth of STEM apprentices had some postsecondary education or technical training at registration, almost four times the rate of their non-STEM counterparts. Despite a higher average educational attainment, STEM apprenticeships are still highly accessible to workers with lower education levels. The majority still had an educational attainment of a high school diploma or less at registration.

TABLE 3

Educational Attainment of STEM and non-STEM Apprentices at Registration, 2000–2016

Apprentices in the Registered Apprenticeship Partners Information Data System

Educational attainment at registration	STEM	Non-STEM
Post-secondary or technical training	19.9%	5.5%
High school diploma	57.8%	68.0%
GED	14.9%	12.1%
9-12th grade, no diploma	3.6%	9.4%
Less than 8th grade	0.2%	0.9%
Unknown or missing	3.7%	4.0%
Total apprentices	13,521	1,511,042

Source: Authors' calculations from the Registered Apprenticeship Partners Information Data System.
Notes: The table excludes a small percentage of registered apprentices with missing occupational information.

Registered apprenticeship is an increasingly common training model for people in prison—particularly STEM apprenticeships. 7.3 percent of non-STEM apprentices are in prisons, compared with 25 percent of STEM apprentices (table 4). Prison apprenticeship programs, both in STEM fields and in other trades, potentially offer people in prison an opportunity to build skills that are valuable in the civilian labor market. However, STEM apprentices in prisons face obstacles that apprentices outside of prison do not. They are paid low or no wages for their work and can only choose from a very limited set of occupations (Hecker and Kuehn 2019).

The share of STEM apprentices who were employed in prison programs varied widely by occupation, with approximately one-half of all science apprentices (53.1 percent) and computer science and information technology apprentices (47.7 percent) in prison and a little over one-quarter (26.5 percent) of all engineering technician apprentices in prison. There were no engineering apprenticeships in prison. Hecker and Kuehn (2019) point out that prison apprenticeship programs are highly constrained by the types of occupations that the confines of a prison facility can support. Computer science occupations are straightforward to offer, given the relatively low cost of computing equipment and the pervasive need for IT services. Almost all the science apprenticeships in prisons are horticulturalist programs operating in greenhouses and gardens maintained by prison facilities.

TABLE 4

STEM and non-STEM Apprentices in Prison Apprenticeship Programs, 2000–2016

Apprentices in the Registered Apprenticeship Partners Information Data System

	STEM	Non-STEM
Programs in prison	25.0%	7.3%
Programs not in prison	75.0%	92.7%
Total apprentices	13,521	1,511,042

Source: Authors' calculations from the Registered Apprenticeship Partners Information Data System.

Notes: The table excludes a small percentage of registered apprentices with missing occupational information.

Although several recent studies have explored the unique circumstances of prison apprenticeships (Hecker and Kuehn 2019; Kuehn 2019; Zessoules and Ajilore 2018), the most comprehensive discussion of STEM apprenticeships in prison to date is included in a consensus report on engineering technology education by the National Academy of Engineering (2017). Using earlier sets of RAPIDS data, the National Academy of Engineering (2017) finds that engineering technicians in prison programs are more likely to be people of color and are older on average than engineering technicians in programs that are not in prison. Apprentices in prison who were registered in engineering technology programs were more likely to hold GEDs (as opposed to a high school diploma) than their counterparts outside of prison, but only somewhat less likely to have had postsecondary or technical training.

STEM Apprentices' Outcomes

Earnings are one of the most important outcomes for registered apprentices. Apprenticeship is a "learn and earn" model of training that allows participants to earn a living while making investments in their skills. STEM apprentices are no different and have the potential to earn considerably more while they are training compared with their counterparts in STEM education programs.

STEM apprentices are better paid than their non-STEM counterparts, both at registration and exit from the program—the two points at which wages are measured in the RAPIDS data (table 5). The apprentices start working at an average of $19.81 an hour, over $3 an hour more than non-STEM apprentices. At exit, STEM apprentices earn over $20.50 an hour. All of these figures reflect the noninstitutionalized apprentice population and exclude apprentices in prison, who earn little or no pay for institutional reasons described by Hecker and Kuehn (2019). If apprentices in prison were included in the average wages, STEM wages would be much lower.

TABLE 5

Starting and Exit Wages (2018 dollars) in STEM and non-STEM Apprenticeship Programs, 2000–2016

Apprentices in the Registered Apprenticeship Partners Information Data System

	STEM	Non-STEM
Average starting wage	$19.81	$16.64
Average exit wage	$20.55	$18.02
Total apprentices	13,521	1,511,042

Source: Authors' calculations from the Registered Apprenticeship Partners Information Data System.
Notes: The table excludes a small percentage of registered apprentices with missing occupational information. Apprentices in prison are not included. Exit wages are not measured for apprentices who are currently registered. All wages are adjusted for inflation.

Some STEM occupations are higher paying than others (table 6). Not surprisingly, the highest paying STEM occupation is engineering. This is followed by engineering technicians and scientists and science technicians. Computer science and information technology apprentices are paid the least (just under $17.50 an hour at registration), although even these apprentices enjoy higher wages than the average non-STEM apprentice.

TABLE 6

Wages by STEM Occupation (2018 dollars), 2000–2016

Apprentices in the Registered Apprenticeship Partners Information Data System

	Average entry wage	Average exit wage
Computer Science and Information Technology	$17.45	$18.52
Engineering Technicians	$19.84	$20.47
Engineers	$21.61	$23.15
Scientists and science technicians	$19.49	$20.12
All STEM apprentices	$19.81	$20.55

Source: Authors' calculations from the Registered Apprenticeship Partners Information Data System.
Notes: The table excludes a small percentage of registered apprentices with missing occupational information. Apprentices in prison are not included. Exit wages are not measured for apprentices who are currently registered. All wages are adjusted for inflation.

Besides wages, program completion rates are another important apprentice outcome. Table 7 reports these rates using the official Department of Labor definition of program completion. The US Department of Labor's DOL-Employment and Training Administration Bulletin 2015–10 defines completion of an apprenticeship program as successful completion within a year of the expected completion date. Apprentices who cancel their apprenticeship or who fail to complete within a year of their expected completion date are considered noncompleters. Apprentices who have not yet reached the date are not included in the calculation of the completion rate.

TABLE 7

Completion Rates in STEM and non-STEM apprenticeship programs, 2000–2016

Apprentices in the Registered Apprenticeship Partners Information Data System

	STEM	Non-STEM
Completion rate	55.1%	33.3%
Total apprentices	13,521	1,511,042

Source: Authors' calculations from the Registered Apprenticeship Partners Information Data System.
Notes: The table excludes a small percentage of registered apprentices with missing occupational information. The US Department of Labor's DOL-ETA Bulletin 2015-10 defines completion of an apprenticeship program as successful completion at some point within a year of the apprentice's expected completion date.

Between 2000 and 2016, 55 percent of STEM apprentices completed their program, which is a much higher rate than non-STEM apprentices (table 7). This success was reflected in our interviews with sponsors and RTI providers. Most respondents did not identify major challenges with retention or completion and estimated high completion and retention rates. The large insurance company sponsoring IT apprenticeships even said that retention was the biggest value add of the apprenticeship model.

More than one respondent indicated that their STEM occupations had higher completion rates than non-STEM, which is consistent with the data reported in table 7. A precision manufacturer explained that “some [apprenticeship] programs have higher turnover than others, but machinist, quality, and die design [the offered STEM occupations], those are solid.” Multiple interviewees suggested that high and consistent pay—including clear pay steps—contributed to high retention.

Besides completion, another concern commonly associated with apprenticeship is that participants will be “poached” by other employers after completing the programs. Some respondents suggested that if apprentices did leave the organization after completion, it was typically for higher-paying positions offered because of their newly acquired skills. One Navy shipyard illustrates this point; while retention was not an issue, apprentices (particularly in the STEM occupation, nondestructive testing) were “promoted right out of the program once they get a certain number of qualifications.” A large insurance company found that “[apprentices] stick around after employment., [but] it does depend on how desirable those jobs are in other organizations and in industry. [I] can think of a couple of areas—cybersecurity, for example—[where] they're highly desirable by other organizations, so that might be concerning, but all the rest are pretty solid.” Despite this observation, the respondent indicated that their apprenticeship program completers had higher retention than their normal hires (about 4 to 5 percent attrition compared with 11 percent). The company attributes lower attrition to the length of the apprenticeship program—“[the] longevity of apprenticeship program keeps them engaged.”

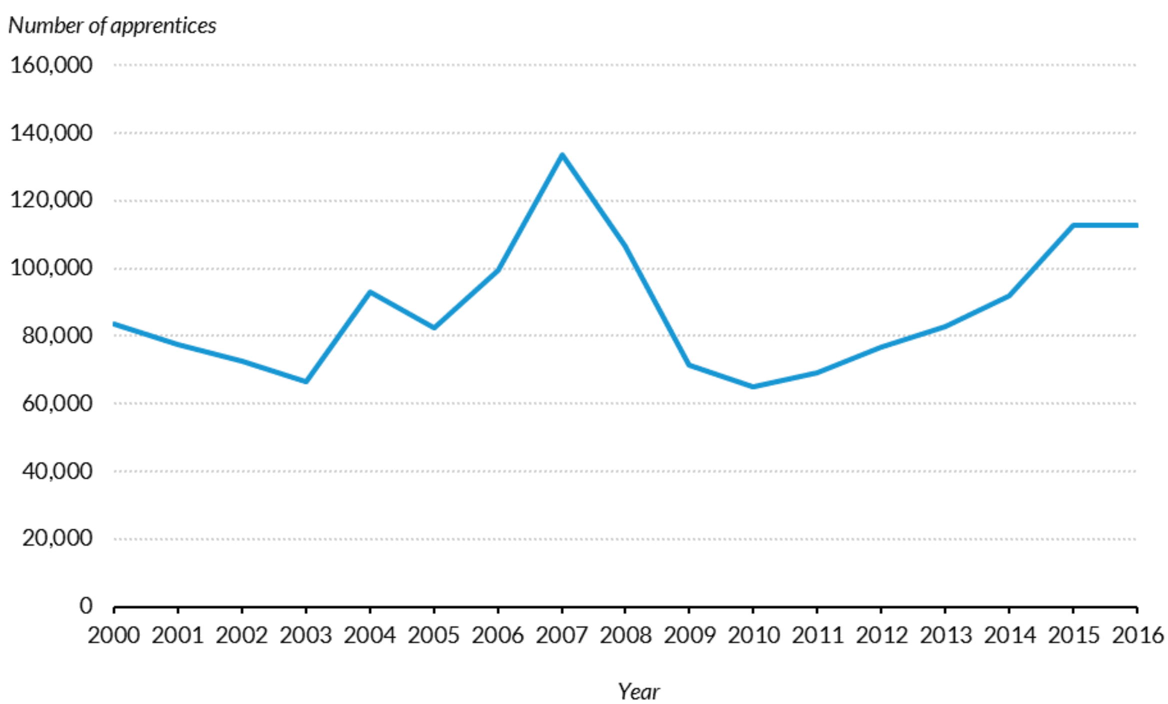
A gas company described similar retention and poaching issues but, interestingly, only occurring internally: “we don't have a problem of them leaving for other companies, have a problem with them leaving within our company, finishing an apprenticeship and doing another one within our company.” The interviewee attributed this behavior to the union, which supported apprentices’ ability to move between jobs and apprenticeship programs in the company. These internal retention problems were a source of frustration for management, which wanted more consistency in its staffing. Despite noting this problem, the interviewee estimated a retention rate of above 90 percent following completion.

Trends in STEM Apprenticeship

With the possible exception of a few engineering technician occupations that are traditional to the manufacturing industry, STEM apprentices fall in the category of nontraditional apprenticeships, so one might expect to see different patterns of new apprentice registrations over time compared with non-STEM apprenticeships. For example, one might expect the number of new STEM apprentices to have been less sensitive to the Great Recession (which was particularly damaging to the building trades) than non-STEM apprentices who were concentrated in the building trades. Since apprenticeship is new in many STEM fields, one might also expect to see lower registration of STEM apprentices in the early 2000's that grows steadily over time.

FIGURE 2

Trends in non-STEM Apprentice Registration, 2000–2016

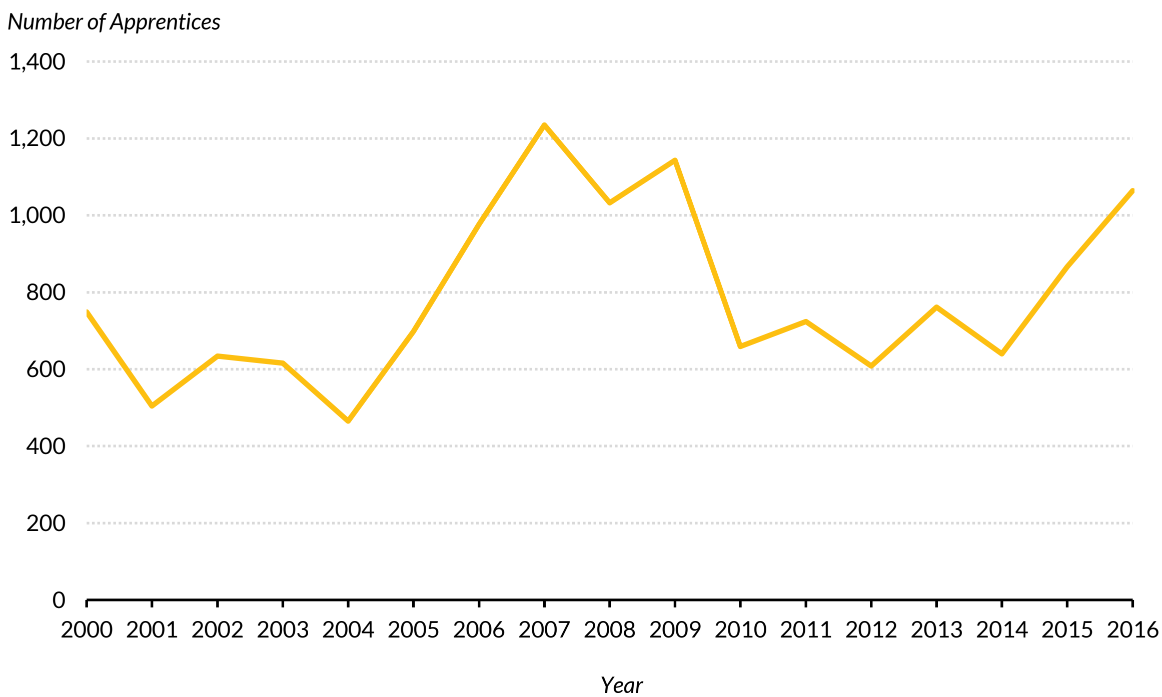


Source: Authors' calculations from the Registered Apprenticeship Partners Information Data System.
Notes: The table excludes a small percentage of registered apprentices with missing occupational information.

These expectations are not borne out by the data in the RAPIDS system. After accounting for the fact that the number of STEM apprentices (figure 3) is much lower than the number of non-STEM apprentices, the trends in STEM registration match non-STEM (figure 2) trends closely. STEM apprenticeships' response to the Great Recession is somewhat delayed compared with non-STEM, but the basic time trends are the same. These patterns reflect earlier work by Kuehn (2016)[6] and Bilginsoy (2018) on the effect of the Great Recession on the registered apprenticeship system.

FIGURE 3

Trends in STEM Apprentice Registration, 2000–2016



Source: Authors' calculations from the Registered Apprenticeship Partners Information Data System.
Notes: The figure excludes a small percentage of registered apprentices with missing occupational information.

Investments in the American Apprenticeship Initiative grants, state expansion and intermediary grants, and the Industry Recognized Apprenticeship Program (IRAP) model of program registration may eventually result in more rapid growth of STEM apprenticeships relative to more traditional trades. Future growth may also be supported by the development of national competency-based occupational frameworks in STEM fields that are pre-approved by the US Department of Labor. These frameworks lay out the content of a competency-based apprenticeship program in an occupation, which employers can use to expedite the development of their own registered apprenticeship programs. Despite these opportunities for future growth, the most recent RAPIDS data available at the time of this study do not indicate an acceleration of registering STEM apprentices relative to the background growth of non-STEM apprenticeship registrations.

Several interviewees suggested that STEM apprenticeships responded to the business cycle and other fluctuations in demand. For example, a staff member at a large shipbuilder's apprenticeship program said that the company had to end its electromechanical design drafter apprenticeship program in 2012 as a result of a reduction in demand. The respondent indicated that while there has been a small surge in demand since the program ended, it hasn't been substantial enough to warrant restarting the program. To fill their needs, the shipbuilder opted to hire directly from community college partner programs rather than reinstate the program because they did not know how long the new needs would last. Since then, the company has considered reinstating the electromechanical design drafter apprenticeship program if demand rises consistently. The representative of the apprenticeship program indicated that reinstating the program at the shipyard wouldn't be difficult because "all we have to do is pull the curriculum off the shelf, make sure it's current and up to date with industry standards, and hire a new class." Although this response reflects confidence about the strength of the apprenticeship program's design, it does not account for the US Department of Labor's practice of canceling programs that have been inactive for several years.

We're seeing a lot of smaller companies coming in and wanting to secure this pipeline. So they're getting at it quickly
—A community college providing related technical instruction to the auto industry

RTI providers for STEM apprenticeship programs commented on cyclical forces affecting apprenticeship. One community college cited a "cycle of downturn in apprenticeships" in the auto industry associated with the Great Recession. They noted that they decreased their own occupational offerings in response to a major apprentice employer consolidating the occupational programs that they offered. During the recovery, the college has seen early signs of new sources of demand. They said that they were "seeing a lot of smaller companies coming in and wanting to secure this pipeline. So they're getting at it quickly."

BOX 1

Naval Shipyard Apprenticeships

Several interviewees sponsored programs at naval shipyards. Programs at shipyards included nondestructive testers, electromechanical design drafters, calibration laboratory technicians, and electronics technicians. In addition to these STEM programs, all the shipyards operated non-STEM apprenticeship programs in welding, pipefitting, HVAC, and other traditional apprenticeable trades. The shipyard programs were frequently identified for interviews because they employ a large number of apprentices. Staff were also more open to participating in interviews than other sponsors. All of the naval shipyards we interviewed were individual programs (i.e., they did not sponsor an apprenticeship with other employers), but some partnered with unions to operate the program. Shipyards operate large apprenticeship programs in multiple occupations, so they typically enjoy the economies of scale that make group programs attractive for smaller employers. One interviewee from a shipyard program said that the programs remained independent so that they could "fit the needs of each particular shipyard." Despite not formally operating as a group program, the respondents from the shipyards are in regular communication with each other and sharing of best practices, frequently holding biweekly conference calls between apprenticeship coordinators at similar institutions. These communities of practice can help to ensure consistency and high standards in apprenticeships. Similarities include:

- All shipyards required applicants to take an Office of Personnel Management civil service test for placement. More than one shipyard apprenticeship program acknowledged declining rates of meeting the required threshold on the test.
- Applicants apply to all apprenticeships at the shipyard, not an individual occupation. After being assessed, an applicant is placed in the most appropriate program. The STEM programs are frequently the most desired apprenticeships because they are challenging and pay well.
- All of the shipyards we interviewed partnered with at least one college to teach the RTI (on or off site) for at least one of their programs.
- All shipyards expressed an interest in moving toward competency-based apprenticeships.

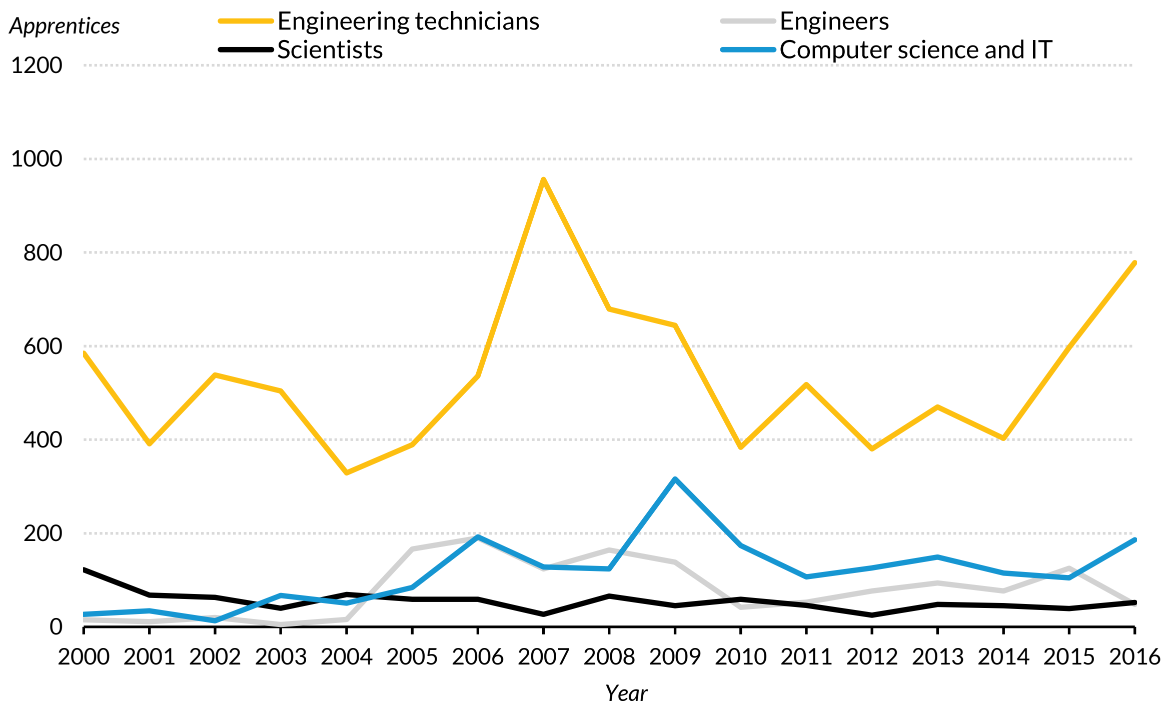
Source: Authors' interviews with apprenticeship programs sponsors.

Trends in apprenticeship registration in STEM vary by occupation (figure 4). Most of the reaction to the Great Recession apparent in figures 2 and 3 is a result of the rise and subsequent decline of engineering technician apprentices, largely in the manufacturing sector. Computer science and IT apprentice registrations peak in 2009, but engineering and science and science technician apprentices are generally not responsive to the business cycle. In 2016 there was an uptick in registration of engineering technicians and IT apprenticeships, and a decline in the registration of engineering apprenticeships.

One interviewee at an RTI provider explained the recent increase in IT apprenticeship registrations based on their own experience. He estimated that in 2018 they had placed 400 software development and IT apprentices (not all of which would have been included in the RAPIDS data) with about 100 to 150 employers. A community college providing RTI in IT apprenticeships also mentioned recent increases in demand but noted that a major disadvantage in IT apprenticeships was that employers "are more interested in the experience [of applicants] than the certification."

FIGURE 4

Trends in Apprentice Registration by STEM Occupation, 2000–2016



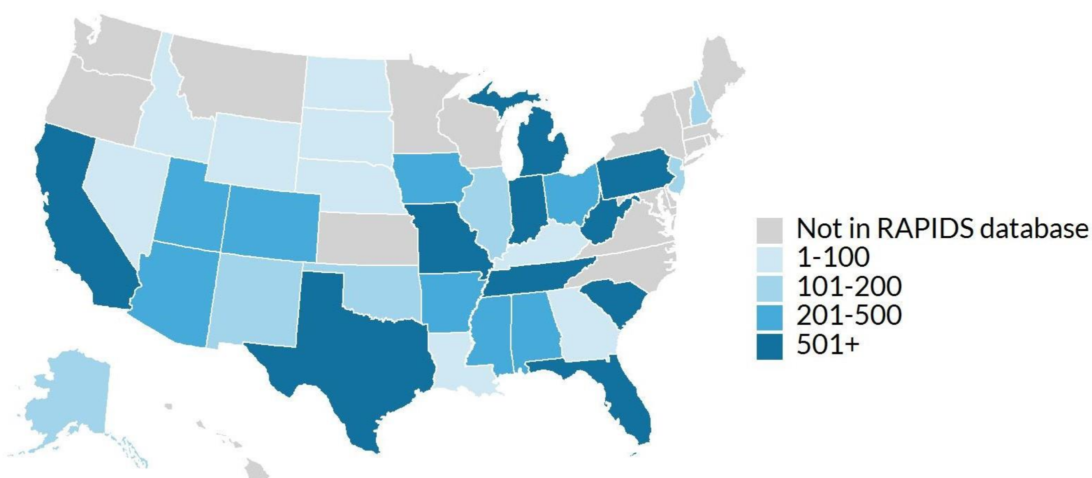
Source: Authors' calculations from the Registered Apprenticeship Partners Information Data System.
Notes: The figure excludes a small percentage of registered apprentices with missing occupational information.

Although business cycle forces are most apparent in figures 2 and 3, STEM apprentices have been shaped by other demand fluctuations as well. A small Alaskan nature conservancy reported variations over time in their ability to open new environmental apprenticeship positions. The program's technicians monitor local use and production of hazardous materials, primarily for oil and gas companies and the military. In the past five years, the sponsor has downsized their program because of cuts in government spending, the declining local military presence, and a depressed oil industry. The sponsor noted that "those jobs dried up and people needed different certifications." However, increased concern about climate change has bolstered demand for environmental technicians with a somewhat different skill set, so the sponsor has adjusted the apprenticeship to meet those needs. Other sponsors also felt more pressure from changes in government spending rather than the business cycle. For example, a Navy fleet readiness center had to stop hiring for its instrument mechanic and nondestructive tester positions (as well as its non-STEM apprenticeships) in response to the 2013 federal government shutdown.

STEM apprenticeships are unevenly distributed across the country (figure 5), with the highest number in California, Indiana, Missouri, West Virginia, and South Carolina. Two of those four states, Indiana and Missouri, operated large prison-based apprenticeship programs in STEM fields that made up a large share of the overall STEM apprentices in each state. In Indiana between 1999 and 2016, 46.8 percent of the STEM apprentices employed were in prison. In Missouri, that figure was 78.9 percent. Those two states accounted for 45 percent of all STEM apprentices in prison in the RAPIDS database. Hecker and Kuehn (2019) provide a detailed discussion of the unique constraints facing prison apprenticeships, including the Indiana and Missouri STEM programs.

FIGURE 5

STEM Apprentices, 1999–2016



Source: Authors' calculations from the Registered Apprenticeship Partners Information Data System.
Notes: The figure excludes a small percentage of registered apprentices with missing occupational information.

In addition to having a large number of STEM apprenticeship programs in prison, Indiana is also home to the Ivy Tech Community College, the community college system for the state, which supports a significant number of STEM apprentices as an RTI provider. Indiana supports apprenticeship programs at Ivy Tech through a generous employment and training services fund (McCarthy, Palmer, and Prebill 2017). Ivy Tech is a nationally recognized provider of sub-baccalaureate technical training, so it is no surprise that the system is important to the provision of STEM apprenticeships in the state. The system has provided related training for employer partners for over 30 years, and trains about 2,000 apprentices a year in nonconstruction sectors.

West Virginia is also a major producer of STEM apprenticeships because of a large Mine Safety and Health Administration (MSHA) program that trains mine inspector apprentices. Although they are not a typical STEM occupation, mine inspectors are classified as mine safety engineers and require considerable engineering knowledge to ensure the health and safety of workers in the mining industry. The MSHA program registered in West Virginia provides a helpful illustration of the difference between the registration of an *apprenticeship program* and an *apprentice*. Although the program is registered in West Virginia, apprentices registered with the program train in several other states, including many in the traditional mining states of Kentucky, Pennsylvania, Virginia, and Colorado. A West Virginia STEM apprenticeship program is therefore involved in the labor markets of many other states, such as Virginia, that are not normally included in the RAPIDS database.

South Carolina and California employ a large number of STEM apprentices because they are active apprenticeship states that are specifically targeting expansion efforts in non-traditional apprenticeship trades. Neither state hosts a large STEM prison apprenticeship program or a showcase program like West Virginia's MHSA program. South Carolina does have an active manufacturing sector that participates in registered apprenticeship. These employers sponsor a fair number of engineering technology apprenticeships in the state.

STEM Apprenticeship Sponsors and Programs

This section discusses the characteristics of STEM apprenticeship sponsors, including details about how their programs are structured. STEM occupations and labor markets are different from non-STEM occupations, particularly the traditional building trades that constitute the bulk of registered apprenticeship in the US. Employers who are interested in starting an apprenticeship program would therefore benefit from learning how others have adapted the apprenticeship model to their needs.

Designing a new apprenticeship program is a major undertaking. Staff at an insurance company that sponsors an IT apprenticeship described how the documentation and paperwork required to start a program could be an important obstacle for prospective employers. One RTI provider for IT apprenticeships told us that because many employers are skeptical of using apprenticeship to invest in STEM skills a “lot of energy is used in the education [of the employers] and thinking through the programs.” One way to help employers is to assess how STEM apprenticeship sponsors structure their programs today.

STEM apprenticeship programs vary in the roles of employers and unions in the program, registering body, the apprenticeship program type (time-based, competency-based, or hybrid), and whether they are operated side-by-side with non-STEM programs.

Apprenticeship Program Models

There are four broad types of programs in the registered apprenticeship system. Independent nonjoint programs involve one employer and are not jointly operated with a union. Independent joint programs involve only one employer but are operated jointly with a union. Group joint and group nonjoint programs involve multiple employers and are, respectively, operated with and without a union partner. These programs are not necessarily sponsored by an employer—and group programs in particular are often sponsored by entities other than the employer (in the case of group joint programs, this entity is often a joint labor-management organization).

The distribution of STEM and non-STEM apprentices across different sponsor types is presented in table 8. Over one-half of STEM apprenticeships (54.3 percent) are employed by independent, nonjoint sponsors. This is not surprising given the low unionization rates in STEM occupations and the high numbers of STEM apprentices in prison.[7] One shipbuilder that we interviewed noted that its quality assurance technician program (classified as STEM) was the only nonjoint program they operated for the simple reason that there was no union to represent those workers. A little over one-third of STEM apprentices (34.3 percent) are employed in a joint program of some sort, compared with 60.7 percent of non-STEM apprentices.

TABLE 8

Program Types for STEM and non-STEM Apprentices, 2000–2016

Apprentices in the Registered Apprenticeship Partners Information Data System

Program Type	STEM	Non-STEM
Independent, nonjoint	54.3%	26.4%
Independent, joint	24.4%	7.1%
Group, joint	9.9%	53.6%
Group, nonjoint	10.0%	12.6%
Unknown or missing	1.4%	0.3%
Total apprentices	13,521	1,511,042

Source: Authors' calculations from the Registered Apprenticeship Partners Information Data System.
Notes: The table excludes a small percentage of registered apprentices with missing occupational information.

Perhaps the most surprising difference is that a smaller share of STEM apprentices (10 percent) are in group nonjoint programs compared with their non-STEM counterparts (12.6 percent). Group programs have been heavily promoted in recent initiatives to expand apprenticeship into nontraditional fields, but these programs can be costly to set up. About as many STEM apprentices were involved with group nonjoint sponsors as were involved with group joint sponsors.

Reflecting the data reported in table 8, most of the sponsors of STEM apprentices that were interviewed were involved in independent programs. An alternative model for group sponsorship that RTI providers mentioned frequently during interviews was that the provider could sponsor a group program. One community college described how they "work with many companies and create a consortium model." They noted that they could not afford to provide RTI exclusively "for individual company-based cohorts," but that by sponsoring a group model with standardized RTI, they could include companies that otherwise would not be able or willing to operate an apprenticeship.

Some of our interviewees represented joint programs. An apprenticeship director from an independent joint instrumentation technician program at a chemical company highlighted the importance of the union's oversight of training quality but also noted the challenges of the joint arrangement. Speaking of the work of the instrumentation technicians, he suggested that "we have engineers that do a lot of this work too… from one standpoint it'd be easier for us if we just had engineers and technicians do this rather than a unionized group doing it. There's a lot of crossover and we get complaints from time to time from the union—grievances because they think the engineers are doing the work the apprentices should do." This concern did not affect the chemical company's faith in the program.

We have engineers that do a lot of this [instrumentation technician] work too… from one standpoint it'd be easier for us if we just had engineers and technicians do this rather than a unionized group doing it. There's a lot of crossover and we get complaints from time to time from the union—grievances, because they think the engineers are doing the work the apprentices should do.

—An apprenticeship director at a chemical company

Although program types are typically the purview of employers and other sponsor organizations, we spoke with a staff member at a community college who noted that the stigma of unions can be a barrier to expanding apprenticeship. Many local companies "don't want any piece of unionism." They found that framing an apprenticeship for advanced manufacturing as a co-op, or even an internship, was received more favorably by the employer. The college also described challenges in explaining the purpose of apprenticeship standards for employers: "some of the standards of work, either healthcare or IT, is just foreign to them."

Competency-Based Programs

Our interview subjects—both sponsors and RTI providers—consistently shared an interest in integrating competency-based education into their STEM apprenticeship programs. Competency-based education marks progress through an education and training program by requiring participants to demonstrate mastery of a set of competencies rather than just logging hours on the job or time in a classroom. This introduces flexibility by allowing stronger apprentices to accelerate through the program and allowing others to spend more time on areas where their knowledge is weaker.

Only 3.9 percent of STEM apprentices were employed in either competency-based or hybrid programs, almost exactly the same share of non-STEM apprentices in these programs (table 9). Thus, despite the interest in competency-based education, little of it is currently occurring in practice.

TABLE 9

Competency-Based Education in STEM Apprenticeship Programs, 2000–2016

Apprentices in the Registered Apprenticeship Partners Information Data System

	STEM apprentices	Non-STEM apprentices
Competency based and hybrid programs	3.9%	3.7%
Time-based programs	96.1%	96.3%
Total apprentices	13,521	1,511,042

Source: Authors' calculations from the Registered Apprenticeship Partners Information Data System.
Notes: The table excludes a small percentage of registered apprentices with missing occupational information.

An apprenticeship director at one of the Navy shipyards shared that "in general, the Navy shipyards would like to move toward competency-based programs, possibly doing a hybrid first" and that they were "looking to include more competencies in [all of their] programs." This sentiment was repeated by staff at another shipyard. As box 1 describes, the shipyards were in close contact with each other and frequently strategized around new instructional approaches like competency-based education.

A large Pennsylvania technology company operating programs in quality control and die design also expressed interest in moving from time-based to hybrid models "so that, if you have young superstars, they can get the certificate more quickly." They reported that the Pennsylvania State Apprenticeship Agency is "always willing to listen if we want to create an apprenticeship option." A South Carolina health insurance company operating computer programmer and networking technician apprenticeship programs reports "looking into potential hybrids, switching from hours to competencies…we're working with Apprenticeship Carolina to make that transition now." Apprenticeship Carolina is a division of the South Carolina Technical College System charged by the state with promoting apprenticeship in collaboration with representatives of the federal Office of Apprenticeship in the state. This sponsor noted that moving apprentices through the program more quickly with competencies might cut down on the tax credit they receive from Apprenticeship Carolina, but that they are nevertheless pursuing a hybrid because the "specific competencies would be more beneficial" for their apprentices.

One RTI provider we spoke with had successfully transitioned from a time-based to a hybrid program in the IT technician field. They smoothly transitioned to a hybrid program and the provider stated that "we validated our preexisting curriculum to the competency needed for the occupation path. The good news is we did not have to change the program."

Some sponsors operated both time-based and competency-based programs. A utility company included in our interviews offers one competency-based program (machinist), with the rest organized as time-based, including their electrical and instrumentation (E&I) technician apprenticeship (a STEM occupation). Although the company asked the apprenticeship director to begin transitioning all of their apprenticeships to hybrid programs, they were told "to hold off." The apprenticeship director overseeing the E&I technician program highlighted the benefits of competency-based programs, noting that "you have people where it just clicks—and you have them sitting at the end just waiting to get the hours. Most people progress faster but some really go fast." He did add that this was not as much of a problem in the E&I technician apprenticeship as it was in other occupations.

Others considering competency-based programs spoke of their potential benefits but also acknowledged challenges. The apprenticeship director at a large aviation center predicted that the transition to competencies would take some time to ensure quality. He mentioned that programs at similar facilities are pursuing competency-based models as well, and that the centers were collaborating with one another to ensure that their programs were standardized.

Despite widespread enthusiasm for competency-based education, not all of the STEM program sponsors and RTI providers were eager to move away from the traditional time-based model. One community college explained that their new IT apprenticeship program is likely to be time-based, because their state "is stuck on the time-based idea, the competency-based approach hasn't caught up. Unions work with us. It's mostly a cultural reason for why we're stuck on the time-based model." The college was also more confident in their ability to develop a time-based program and get it approved. The interviewee shared that they "only have one program of study that's competency based. We've been cautiously optimistic about the time it takes to create them and then for the time it takes to get it through the federal government. It's much easier to look at the credit hours and the contact hours, and then apply them to a set of related trainings and see if the clock hours meet the trade-specific functions." Although this college was one of the only interviewees to state their hesitance of the competency-based approach, most of the others rejected it in practice as well.

On-the-Job Training and Related Technical Instruction

All apprenticeship programs must develop a plan for delivering at least 2,000 hours of OJT and 144 hours of RTI. These trainings constitute the core of the programs. RTI delivers more theoretical competencies that are best taught in a classroom, while OJT teaches more practical knowledge at the work site and is overseen by a mentor. Both RTI and OJT can be expensive, so key principles of STEM apprenticeship, RTI, and OJT can help prospective program sponsors plan training.

A representative for a RTI provider for IT apprenticeships spoke positively about the ability of the apprenticeship model to fulfill employer needs in the software development space. He stated:

> "the thing with software development is that there is such a wide variety of programs to learn. So companies have a hard time hiring for specific needs. I think in software development, which is higher skilled compared to other apprenticeship programs, there is a heavy burden of education upfront because there is a lot of information that needs to be learned before someone starts. Once someone has that education, they can work."

OJT in particular is the source of many intrinsic strengths of the apprenticeship model. A staff member at a community college shared that "what I found was that when talking to employers, that they [apprentices] are so much farther ahead coming out of any school because of the OJT." An interviewee at another community college emphasized the importance of apprentices being productive employees and the relationship between teaching the RTI and the OJT in a STEM apprenticeship:

> "I think from a teaching perspective, I think it's easier. I think it's easier because that's the whole model on how the training is provided. The students themselves have a job, so they have that security. So, it's different than someone who is taking courses with the hopes of getting a job. It's different, just a different vibe… when we come back to the classroom they're talking about the on the floor experience and I hear them talking about the technical things they've seen. And now they're engaged in a different way."

A repeated theme of the interviewees was that OJT and RTI focused on providing practical skills, but were also adapted to the unique needs of employer. A large insurance company with software engineering apprenticeships described teaching Java programming, code troubleshooting, internal systems, distributed computing platforms, COBOL programming, and network diagnostics. They teach communications skills in addition to the programming curriculum, but they do not teach math (normally an important part of a computer science degree program), even in the RTI portion of the apprenticeship. This employer had no need for math instruction because its apprentices are all graduates of two- and four-year degree programs in math or computer science, so they are expected to already have sufficient math skills.

The apprenticeship director at the utility program training E&I technicians shared that the company used RTI and OJT to rebalance an inconsistently skilled workforce. He indicated that "the company has tried to hire a combination E&I in the past and they get either an E [electrician] or an I [instrumentation], they don't get both. They spend the next few years informally training in the skills they are lacking."

Interactions with Non-STEM and Unregistered Apprenticeships

A sponsor's prior use of apprenticeship in a non-STEM occupation could be instrumental in successfully establishing a STEM program. For example, a construction company might have a long history of sponsoring apprentice electricians before sponsoring an engineering program, or a manufacturing company might sponsor millwright apprentices before starting an industrial engineering technician apprenticeship. Sponsors with prior registered apprenticeship experience could more effectively avoid the pitfalls of the registration process and apprenticeship standards development. These sponsors may also have a more developed workplace culture in support of apprenticeship and on-the-job training.

Fifty-seven percent of STEM apprentices are employed in programs operated by sponsors who also sponsor non-STEM programs (table 10). The STEM programs are generally smaller than the non-STEM programs operated by the same sponsor.

TABLE 10

STEM Apprentices Registered with Sponsors of Non-STEM Programs, 2000–2016

Apprentices in the Registered Apprenticeship Partners Information Data System

	STEM apprentices
No non-STEM program operated by sponsor	42.6%
At least one non-STEM program operated by sponsor	57.4%
Total apprentices	13,521

Source: Authors' calculations from the Registered Apprenticeship Partners Information Data System.
Notes: The table excludes a small percentage of registered apprentices with missing occupational information.

The interviewees associated with both STEM and non-STEM programs generally felt that the apprenticeship model is as effective in the STEM occupations as it is in other fields. A large shipbuilder explained that "there is no difference… it's on-the-job training no matter what field, balanced with a classroom portion," and that "balancing those two is the same for each program."

That's how we train pilots and doctors.
—A staff member at a state technical college that provides RTI

One community college providing RTI for several different STEM apprenticeship programs mentioned that while there's little difference between STEM and non-STEM apprenticeships from a teaching standpoint, many of their industry partners did not think of the STEM programs as apprenticeships. Employers assume that apprenticeships are exclusive to the building trades and some manufacturing jobs. Interviewees from the community college RTI providers rejected this stereotype and described the arguments that they present to employers of STEM workers. A staff member at a state technical college said that apprenticeship and work-based learning is, "how we train pilots and doctors," so it should be appropriate for difficult STEM occupations as well.

The apprenticeship director at a utility company operating the E&I technician apprenticeship and several non-STEM occupations noted that all of their programs were difficult but that the E&I technician program was the toughest. "I went through the machinist program," he shared, but "E&I is definitely the tougher of the four" programs that the company operates.

Recruitment

STEM sponsors recruited apprentices in a variety of ways. Several noted that recruitment was easy; a large shipbuilding company said that they receive "7,000 applicants a year for 200–300 openings," and a Navy shipyard echoed the sentiment: "we have lots of applicants—thousands every year…recruiting is easy because it's a well-paying job." Shipyard recruitment differs from other apprenticeship programs because applicants are assigned to an apprenticeship depending on their aptitude; they do not apply to specific occupations. In fact, only a small portion of those applicants will ultimately be hired as STEM apprentices.

Many apprentices are recruited from local high schools, community colleges, and technical schools. An energy company sponsoring a STEM program recently started a preapprenticeship program to use as a recruitment source, but it struggled to obtain insurance for workers under age 18. A chemical company did not recruit externally for their apprenticeship at all; rather they only provided apprenticeships for existing workers.

One nonprofit operating an environmental technician apprenticeship program opened apprenticeship applications as grant funds were secured for each program, and it noted that the grant funds' minimum qualifications for participants dictated the prerequisites in any given case.

STEM Apprenticeship RTI Providers

In addition to employers, the other important role in an apprenticeship program is the RTI provider. RTI providers supply the shorter, but vital classroom training component of the program. Like other apprentices, STEM apprentices, receive at least 144 hours of related technical instruction (RTI). Many types organizations can be RTI providers, from community colleges or private training providers, to unions or employers. Some information on RTI providers is collected in the RAPIDS database, but these data are much less complete than the information on apprentices and programs.[8]

We reclassified all STEM apprenticeship RTI providers in the RAPIDS database to get a more reliable and complete picture. (table 10). Despite extensive discussion of community colleges as apprenticeship partners, only one-third of STEM apprentices got their RTI from a college. Another 11.7 percent got RTI from a noncollege education and training provider. These institutions ranged from an adult basic education program to private trade schools. Almost one-quarter of STEM apprentices received their RTI from prisons that served as both the program sponsor and RTI provider. Although over one-third of STEM apprentices are employed in joint programs, only about 4 percent receive their RTI from the union or joint apprenticeship training committee (JATC). After prisons and colleges, the most common RTI provider was the apprentices' employer (21.8 percent).

TABLE 11

STEM Apprentices by RTI Provider Type, 2000–2016

Apprentices in the Registered Apprenticeship Partners Information Data System

RTI Provider Type	STEM apprentices
Colleges	33.0%
Non-college education and training provider	11.7%
Prison (sponsor)	24.0%
Military	2.9%
Professional association or group program	2.0%
Union or JATC	4.1%
Employer	21.8%
Other	0.3%
Total apprentices	13,521

Source: Authors' calculations from the Registered Apprenticeship Partners Information Data System.
Note: The table excludes a small percentage of registered apprentices with missing occupational information.
bold.

Although only one-third of STEM apprentices received RTI from a college, some interviewees expressed an interest in exploring what community colleges have to offer. A chemical company training apprentices in instrumentation described some challenges with their current RTI scheme. They offer RTI through instruction books published by a third party, but have "talked at times about taking [the RTI] out of the books and aligning with a local community college where they go through courses. We're not positive the work on your own book style is the best."

Colleges providing RTI that we spoke with are experiencing growth in STEM apprenticeships. A representative of a state technical college described how their chemical operator apprenticeship program, which started at only five apprentices in 2017, grew to over 100 apprentices in 2018. That recent growth would not have been captured in the RAPIDS data reported in this study. The same college provided RTI for apprenticeships in industrial maintenance for a paper company and an electrotechnical technician program, and was starting a new IT apprenticeship program.

The apprenticeship director at the fleet readiness center reported providing their RTI in-house, in part because of the scale of their programs. The center's STEM occupation, a nondestructive tester program, was even housed in the training department of the center because of its intensive training requirements (as opposed to being housed with the production group like the non-STEM programs). The apprenticeship director for this program reported that it was difficult to retain RTI instructors for the nondestructive program because the requirements for the instructors were so high.

Design of RTI

The design of RTI varied across the STEM apprenticeship programs we interviewed. Generally, program administrators reported delivering RTI in a way that matched the unique needs of their program. For example, apprentices in prison were self-taught out of textbooks, a natural fit given the limitations of facility. Some employers who provided their own RTI standardized it across multiple occupations for their first-year apprentices and then differentiated the curriculum by occupation in subsequent years. An employer that used this approach also had a contract with a smaller local apprenticeship program to provide RTI to their apprentices. Other employers offered a mixture of in-house RTI and externally sourced RTI. This approach was used by a large energy company operating a gas technician apprenticeship program. The apprenticeship coordinator for that program spoke about "bringing in vendors or sending [apprentices] out to class at community college for the computer stuff," clarifying that RTI is "mostly in house." The vendors used for RTI training at the employer's facility were equipment vendors providing practical, hands-on classes on the proper use of their equipment.

A representative of a large insurance company operating IT apprenticeships described their RTI as "blended," clarifying that "we do some RTI ourselves, sometimes we use other organizations." For their computer programmer program, the organization mentioned that they used to use a technical college but have since hired their own instructors to replace the more expensive external trainings. The cost of RTI training was a common challenge highlighted in the interviews. A Naval shipyard also mentioned that they used to contract out for training for a calibration position, but that "we decided we could offer the same training in house, so that stopped."

RTI providers at community colleges were often able to use existing programs at the college for the apprenticeship program. A community college providing RTI to an IT program shared that "we used the existing degree program. The vast majority [of the apprentices] were in the programmer occupation and even the networking, they just fit nicely" into the degree program. While the RTI was designed "way back in the beginning," the college does "some minor tweaks and always reviews the curriculum when apprenticeships start."

Even when sponsors do rely on community colleges for RTI, they can be actively involved in the instruction. A large shipbuilder used a local community college for RTI, but mentioned that "most of their team were former employees" of the shipyard. Whenever the school redesigns the curriculum for the RTI they "ask for us to have a rep in the room for the industry viewpoint."

Another community college working with multiple apprenticeship programs described how they work with employers to develop a unique RTI package to fit their needs, "I'll go back to Chrysler. They want the RTI for credit and we talk to the unions and negotiate and they'll come to common commitment. We're working with Kroger on the bakery and dairy side and they want RTI functions, so there is a curriculum at the degree level and to show them that's this is the best fit for them. We can run it both ways, for credit or not. If a company does not care and wants it done in another format then we can go to a noncredit format."

Integration of OJT and RTI

Several of our interviewees reported that the OJT and RTI for their STEM apprenticeship programs were closely coordinated and linked together. A representative of a Naval shipyard discussed how every hour of the classroom-based RTI training was associated with two to four hours of on-the-job training in safe environments called "mock-ups." The apprenticeship director at a utility company said that their E&I technician OJT and RTI were highly integrated, stating that the "best way I can describe that is that it's all related." He went on to discuss how a journeyperson on the job signed off on the competencies that were taught during the RTI. A representative of an energy company operating a gas technician program also described its RTI and OJT as "very closely integrated." In that case, the company's journeypersons were also the RTI instructors.

One Navy shipyard uses exams to "keep a good eye" on their apprentices' performance in RTI. They also require monthly evaluations that document the type of work and courses taken for that month, as well as a performance rating by the apprentice's mentor. The apprenticeship coordinator shared that,

> "if we have someone who is not performing where they should be or needs additional work that's a good opportunity to nip it in the bud and get some additional training and whatever help they need. We keep pretty good tabs on them. If the supervisors are keeping on top of them it allows us to keep them where they need to be knowledge wise."

Alternatively, some STEM program sponsors only interacted with the RTI side of the program if conflicts arose. Another apprenticeship coordinator at a Navy shipyard suggested that they, "only know [about how apprentices are doing in RTI] if they're not doing well, if someone needs academic help." A community college described a similar arrangement by noting that, "there is a contact person in the state who we speak with through the HR office and if there's any issues. But for most part the supervisor just oversees the OJT."

RTI Content

The extent to which various subjects were taught in STEM apprenticeship RTI varied across programs. One utility company taught "some mathematics…[and] a basic electricity class," required college algebra, and at least one semester of AC theory for incoming participants. All of the RTI was also mapped onto National Center for Construction Education and Research training booklets for industrial maintenance, industrial, and implementation technician programs, which were used on the job. A Navy shipyard operating a large nondestructive tester program said that apprentices took algebra (including some trigonometry and geometry), physics, metallurgy, and materials courses at local colleges for their RTI. Math, blueprint reading, basic hand tools, and part layout—taught in both the RTI and OJT—were the "four principal cores for any apprenticeship we do here," by a precision manufacturer. A chemical company operating an apprenticeship program in instrumentation mentioned that the most advanced courses they teach in RTI are technical algebra, heating and cooling, electrical, logic, measurements, and some computer skills. An apprenticeship coordinator at one of the federal prisons described some of the most difficult math coursework of all the programs, including calculus. Their stationary engineer apprenticeship is "the hardest one, lot of materials, lot of math."

Not many interviewees mentioned lab work as a part of their RTI, perhaps because the OJT training served the usual function of labs in a college program. One RTI provider discussed an industrial operations program that includes "heavy lab work," in addition to online content and proctored testing.

Evaluations of STEM apprentices' performance in RTI were often identified as a key to effectively administering programs. One community college providing RTI utilized a 30-60-90-day evaluation. The instructor writes up student engagement notes and a representative from the college talks to each apprentice one on one at each benchmark period. The utility company with the E&I technician program described a peer evaluation system in which the apprentice meets with their mentor, a journeyman, and their supervisor once a month. A Navy shipyard program uses a system of "need-based evaluation," where each apprentice is evaluated monthly, and "those who don't make satisfactory scores are highest priority."

> Some interviewees indicated that RTI differed between STEM and non-STEM occupations, and specifically that STEM RTI was more difficult. For instance, a large Navy shipyard representative told us that the STEM occupations "typically [require] more trade theory hours than [the] other trades, especially calibration" apprentices. Another shipyard apprenticeship program administrator conveyed that STEM and non-STEM are comparable, but that (referencing their nondestructive tester [NDT] occupation, a stem occupation) "it's kind of trying to compare apples to oranges because the type of work is so drastically different from most of the other trades. The amount of time allotted for the training is the same…our NDTs have pretty rigorous qualifications that they have to maintain." A chemical company providing instrumentation apprenticeships echoed the sentiment, explaining that it is "the most difficult of [the]apprenticeship programs [we offer] based on technical information."

Challenges and Recommendations

Although experiences with STEM apprenticeships to date have been positive, registered apprenticeship has not been a prominent training model for the STEM workforce. Those apprentices that are in STEM fields are better paid and have higher completion rates than their non-STEM counterparts. Program sponsors are broadly satisfied with their STEM apprenticeships. Nevertheless, our research identifies certain challenges that these programs face. Understanding those challenges and experiences can provide important guidance for successful future application of the apprenticeship model to STEM education and training.

Costs and Registration

Employers are concerned about the costs of registered apprenticeship, including the financial costs of RTI, the required time commitments, and the difficulties associated with program registration. Current STEM apprenticeship sponsors typically believe the benefit of apprenticeship is worth the cost, but indicated that other employers may be dissuaded.

One community college providing RTI for IT apprenticeships described how they lost ten of their twelve participating IT employers because of the costs of the program. The representative of the program at the college noted that "There's a large need for IT employment," but that "it's hard to get employers on board for 4,000 to 6,000 hours." A utility company also highlighted costs and time as a challenge in running their E&I technician program. They estimated that, including wages, the 8,000-hour program cost $350,000 per apprentice, with the large majority of costs attributable to wages. This sponsor also mentioned difficulties around program registration. The apprenticeship director noted that "it took quite a bit of time to send it through the state" for approval.

A nonprofit that provided RTI and program registration assistance to IT apprenticeship programs also highlighted registration difficulties. A representative told us that a "lot of energy is used in thinking through the [design of] programs." Their solution to the program registration barrier was to act as a group sponsor for smaller employers that had difficulties registering on their own. The group program approach is a commonly cited solution to the difficulties of program registration, but relatively few STEM apprenticeship programs are organized as group programs. Many STEM apprentices are registered with programs associated with prisons or large shipyards (which typically register as independent programs), or they are registered as engineering technicians in independent manufacturing companies. Cultivating and promoting group sponsorship should help relieve some of the costs of program registration.

A newer option for reducing program registration costs and scaling STEM apprenticeships is to register programs with industry certifiers as "industry-recognized apprenticeship programs" (IRAP). IRAPs are certified by private industry-based organizations rather than the US Department of Labor or state apprenticeship agencies. Ideally, IRAPs would avoid delays in registration and unnecessary red tape, and they may be especially important for bringing existing, unregistered on-the-job STEM training activities into the apprenticeship system. But the IRAP approach is untested and raises many questions. Jacoby and Lerman (2019) point out that IRAP assigns many conflicting roles to the industry certifiers that may reduce their effectiveness. Training quality may also be weaker without government supervision, and IRAPs could conceivably generate an inefficient proliferation and duplication of apprenticeship standards.

Standards and Competencies

Standardized STEM occupational frameworks were a concern for a community college that provided RTI for STEM apprenticeships. They shared that "it's very difficult because the skill set is not clearly defined. You're a network engineer at one company and then you move to another, you'll be doing the same thing but a complete different program is used. It's like learning Spanish for one company and then having to learn German at another." The college representative indicated that this was particularly problematic for their IT apprenticeships. He shared that they often "can't determine what training needs to happen. If we can't make it through that, it's hard to create training. It's hard to sit down and make decisions and we'll all shooting from the hip. There are benefits to doing [apprenticeship], but it's more difficult up front."

Program design decisions do not stop with program registration, since apprenticeships are constantly evolving to meet emerging needs. For example, most of the STEM apprenticeship sponsors we interviewed were interested in transitioning their time-based apprenticeship programs to competency-based programs, or at least hybrid programs that make use of competencies. Despite broad interest in competency-based programs, the large majority of STEM apprentices are in time-based programs. Sponsors reported that designing competencies was complex and time-consuming, and that reregistering as a competency-based program would come with the same paperwork and other costs as registering the program in the first place. One way to overcome these barriers is to make use of existing, approved competency-based frameworks, such as the Urban Institute's National Competency-Based Occupational Frameworks. The Urban Institute frameworks currently include several IT occupations.[9] The National Science Foundation or the US Department of Labor could support the expansion of registered apprenticeship into STEM fields by funding the development of additional preapproved STEM occupational frameworks.

Despite these challenges, the sponsors we interviewed overwhelmingly considered registered apprenticeship to be a critical tool for cultivating STEM skills. Too often, the national conversation around STEM education and training focuses on degree programs at colleges and ignores the wide range of STEM jobs that could be better served by a robust system of registered apprenticeship programs.

Notes

[1] The share of the US population living the states included in RAPIDS was calculated by the authors from 2017 Census Bureau population estimates.

[2] At the beginning of the study we expected new RAPIDS data after 2016 to become available, but the US Department of Labor has transitioned to a new administrative data system—"RAPIDS 2.0"—and is not currently releasing data for research purposes.

[3] In this section and elsewhere in the report we discuss gender in binary terms because the available data on registered apprentices only collects data in this format. The authors acknowledge this language can be harmful to non-binary or gender non-conforming people, and we remain committed to employing humanizing language whenever possible. Similarly, information on apprentices' race and ethnicity are collected jointly in the available data, and in the level of detail provided in this report. We recognize that even these race and ethnicity categories could be reported more granularly, although the size of the RAPIDS database does provide us with an opportunity to report more detailed race and ethnicity categories than are available in many public data sources.

[4] Author's calculation of women's share of employment in February, 2019, from the March 8, 2019 Employment Situation News Report from the US Department of Labor, Bureau of Labor Statistics, accessed March 14, 2019, https://www.bls.gov/news.release/archives/empsit_03082019.htm.

[5] Author's calculations from American Community Survey tables produced by the Census Bureau, United States Census Bureau, accessed March 14, 2019, https://factfinder.census.gov/bkmk/table/1.0/en/ACS/17_1YR/B03002/0100000US.

[6] Kuehn, Daniel. "Three Essays on Connecting to Work" (doctoral diss., American University, 2016).

[7] Prisoners are not unionized (i.e. nonjoint) and in practice, prisons have not implemented group-based programs.

[8] Apprentices and apprenticeship programs, unlike RTI providers, must register with either the federal Office of Apprenticeship or a State Apprenticeship Agency. The registration process is an important source of data on and leverage over the apprenticeship sponsor, which ensures better administrative data. RTI providers, in contrast, do not have to register with any office, so there is less of an opportunity to force RTI providers to supply accurate data.

[9] "Competency-Based Occupational Frameworks for Registered Apprenticeships," Urban Institute Center on Labor, Human Services, and Population, accessed March 14, 2019, https://www.urban.org/policy-centers/center-labor-human-services-and-population/projects/competency-based-occupational-frameworks-registered-apprenticeships.

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About the Authors

Daniel Kuehn is a research associate in the Urban Institute's Income and Benefits Policy Center. He has 13 years of experience conducting and managing research on employment, education and training, apprenticeship, the science and engineering workforce, racial disparities, and the transition from school to work. He primarily conducts quantitative empirical work with an emphasis on nonexperimental evaluation methods. Kuehn also has experience doing qualitative research, and much of his quantitative research experience has been on mixed-methods projects. Kuehn graduated with a BA in economics and sociology from the College of William and Mary, an MPP in labor market policy from the George Washington University, and a PhD in economics from American University.

Ian Hecker is a research assistant in the Income and Benefits Policy Center at the Urban Institute, where he studies the shifting nature of low and middle-wage jobs to help understand and replicate effective policies and programs. Hecker's research covers apprenticeship programs, the Workforce Innovation and Opportunity Act, funding mechanisms for supporting skills development, and automation & the future of work. He also provides strategic support to the coordination and management team for the JPMorgan Chase & Co. New Skills at Work Initiative, and provides data and evidence technical assistance to both government and nonprofit actors. Hecker graduated with a BA in public policy from the University of Michigan.

Alphonse Simon is a research assistant in the Income and Benefits Policy Center at the Urban Institute. His research focuses on workforce development and education policy. Previously, he was a research associate for the microeconomics division at Columbia Business School. Simon received a BA in economics from the University of California, Berkeley, and graduated with high distinction.

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