Research Report

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An Analysis of Education and Training Programs in Advanced Manufacturing Using Robotics

The push to automate manufacturing processes is nothing new, from the advent of assembly lines in the early 20th century to today's autonomous robots that can work together with a single human supervisor. Autonomous robots are just one of many technologies in advanced manufacturing (AM), with AM representing "a family of activities that (a) depend on the use and coordination of information, automation, computation, software, sensing, and networking, and/or (b) make use of cutting edge materials and emerging capabilities enabled by the physical and biological sciences" (President's Council of Advisors on Science and Technology, 2011, p. ii). However, advanced industrial robots are a key and growing AM technology. In 2015, $12 billion worth of industrial robots were sold in the United States. This rate is projected to increase to $22 billion by 2025 (International Federation of Robotics, 2016).

Although robotic automation likely offers manufacturers opportunities to enhance production and remain competitive, many stakeholders are concerned about how a surge in robotic capabilities will affect the human workforce in manufacturing. Will there be room for both humans and robots in new forms of manufacturing? And what skills will humans need to keep pace with anticipated rapid advancements in AM technology?

KEY FINDINGS

- There is a critical need for better and more-integrated workforce data systems that support data-driven policies for building a better AM workforce. This need can only be addressed by all stakeholders, including employers.
- A weak or absent policy response to the transition to AM with robotics in the short to medium term might aggravate negative impacts for less educated and vulnerable workers or fail to draw the large, skilled workforce needed by employers.
- The number of AM-related education and training programs is growing, but, based on newly available data, many programs do not offer field-based experience, industry-based credentials, or an emphasis on nontechnical "21st-century" skills (e.g., problem-solving and dependability and reliability).
- Based on the available research evidence and federal guidelines for determining quality research evidence, the most-promising practices in education and training programs in AM using robotics include industry-based credentials, apprenticeships, and student support services. Program providers should continue to experiment with the exact format of these practices, while conducting rigorous evaluations of them.

This research was sponsored by the Advanced Robotics for Manufacturing Institute.

Most projections suggest that there will be plenty of manufacturing positions for humans to fill—but that these positions will likely require a different set of skills from before, including what have been referred to as *21st-century skills*.[1] One estimate suggests that nearly 4.6 million manufacturing job openings will require filling, with as many as 2.4 million openings going unfilled as the result of a shortage of workers with the necessary technical and nontechnical skills that advanced technologies will require (Giffi et al., 2018).[2] This in turn could potentially result in the average U.S. manufacturer losing 11 percent of its annual earnings, or $3,000 per existing employee, because of skill shortages (Accenture and the Manufacturing Institute, 2014).

Abbreviations

AM	advanced manufacturing
ARM	Advanced Robotics for Manufacturing Institute
ASAP	Accelerated Study in Associate Programs
CIP	Classification of Instructional Program
CTE	career and technical education
CUNY	City University of New York
ETA	Employment and Training Administration
GAO	U.S. Government Accountability Office
IFR	International Federation of Robotics
IPEDS	Integrated Postsecondary Education Data System
MAC	Manufacturing Assistance Center
MEP	Manufacturing Extension Partnership
MOOC	massive open online course
NAICS	North American Industry Classification System
O*NET	Occupational Information Network
OECD	Organisation for Economic Co-operation and Development
SMART-ER	Smart Manufacturing and Advanced Robotics Training—Extended Reach
WWC	What Works Clearinghouse

Study Purpose and Organization

There is much information and misinformation about the future of work as it relates to robots and jobs in manufacturing. The Advanced Robotics for Manufacturing Institute (ARM) engaged the RAND Corporation to review and assimilate publicly available information on this topic with a goal of coalescing data and trends. This report should inform ARM's membership, others in the robotics industry, and the wider policymaking community in their approaches to managing workforce issues.

RAND was asked to assess the state and future of education and training for AM with robotics, with a special focus on the U.S. Midwest region and the adjoining state of Pennsylvania. These areas currently are and historically have been hubs of U.S. manufacturing (see the next section). In AM more generally, programmable robots are dedicated specifically to such industrial uses as welding, painting, assembly, and general manipulation of objects. Because these industrial robots automate many routine tasks previously performed by humans, workers on a national scale are required to have a different set of specialized skills from those required for traditional manufacturing jobs (Modestino, 2016). For this report, we examine the broad economic context in which education and training programs currently operate and potentially will operate in the near future; review available AM programs and evaluate their curricular content and instructional practices and technologies; and review research evidence on promising practices in these areas. The findings from this analysis result in several recommendations for stakeholders to consider as they move forward to meet the opportunities and challenges in AM using robotics in the new decade.

In the next section, titled "The Economic Context of Training in Advanced Manufacturing Using Robotics," we examine the economic context in which education and training programs in AM using robotics operate now and potentially will operate in the near future. The economic context provides critical information for understanding AM-related education and training programs in the United States presently; the needs in the future; and how such programs might be improved to meet these needs and enhance U.S. economic competitiveness in manufacturing. In the section titled "The Landscape of Education and Training Programs in Advanced Manufacturing Using Robotics," we assess the available AM programs nationally and evaluate the curricular content and instructional practices and technologies for a sample of these programs in the Midwest and Pennsylvania. Detailed, primary data on these aspects of AM-related programs provide early and unique insights into how such programs might or might not address the potential skills gap in AM in a U.S. manufacturing hub. The section titled "Promising Practices in Education and Training for the Advanced Manufacturing Workforce" reviews research related to promising practices in AM education and training. Finally, the last section, "Conclusion and Recommendations," summarizes the findings of our study and offers policy recommendations based on the research documented in this report.

The Economic Context of Education and Training in Advanced Manufacturing Using Robotics

Rarely a week goes by without the popular media commenting on the potentially worrisome effects of robotics and other automation technologies on human labor and economic well-being (e.g., see Kinder, 2018; Lepore, 2019). Will robots displace large segments of the workforce, and how can the workforce prepare for the increasing adoption of robots throughout the U.S. economy? Uncertainty about the answers to such questions makes it challenging for education and workforce development programs to identify and respond to training goals adequately and with agility—especially in manufacturing.

In this section, we examine the economic context of AM and robotics, focusing on the economic implications for related education and training programs, given existing research. We pay particular attention to how economic trends and the effects of robotics depend on specific geographic locations and industries. Such considerations are sometimes missing from larger discussions about education and training needs of the AM workforce. Yet acknowledging and addressing these differences are critical for creating a comprehensive approach to workforce development (e.g., see Zaber, Karoly, and Whipkey, 2019). We therefore aim to provide a broad picture of the growth of AM using robotics in the United States, both nationally and regionally, before discussing the available research on the economic impacts of AM in the United States and elsewhere.

Data and Methods

For this part of the report, we reviewed the available research focused on growth in employment, wages, productivity, and other economic metrics across a variety of AM industries and geographic regions in the United States. When relevant, we use the North American Industry Classification System (NAICS) to define and compare industry groups within AM.[3] We define geographic regions according to guidelines provided by the U.S. Census Bureau's 2010 region definitions (see U.S. Census Bureau, 2018). In some analyses, we use data from the International Federation of Robotics (IFR), a professional nonprofit organization that aims to promote and strengthen the robotics industry worldwide.[4]

We organized the findings of our analysis by two key topics: (1) trends in AM and (2) economic impacts of AM across firms, consumers, workers, and the national economy.

Findings: Trends in U.S. Advanced Manufacturing and Their Geographic and Industry Differences

After decades of gradual decline, manufacturing employment in the United States only recently has begun to increase again. Growth has been slow, however, and as of early 2020, overall employment in the sector is still far behind pre–Great Recession numbers (U.S. Bureau of Labor Statistics, undated). Notably, over the past decade, the specific trends in manufacturing employment have been quite variable by location. Although the number of manufacturing jobs has declined in some parts of the country, especially in parts of the Northeast and the West, many locations in the Midwest and the South have seen notable increases in the number of manufacturing jobs after 2008 (Mellnik and Alcantara, 2016).

To gauge recent developments specifically in AM, it is also useful to examine trends in automation technologies, such as industrial robots. In this section, we examine notable patterns related to past growth in the supply of industrial robots across Census regions and industries.

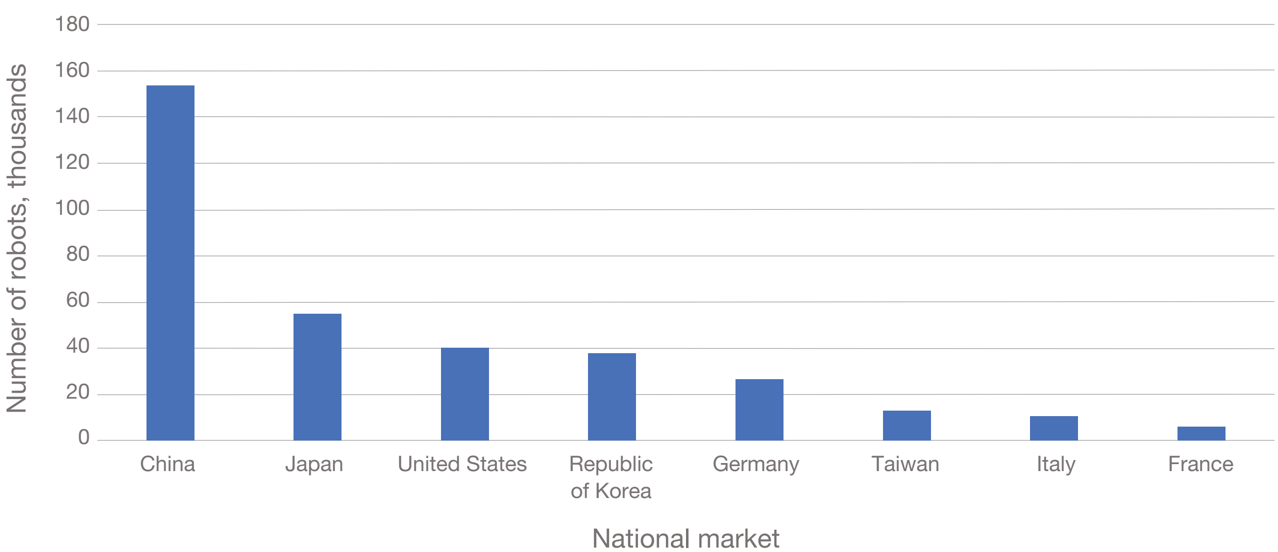
The United States is not keeping pace with other countries in the recent adoption of robots. Overall, the United States has a higher stock of industrial robots than many countries, including China (217 robots per 10,000 workers in the United States versus 140 robots per 10,000 workers in China). IFR data demonstrate, however, that robot installations in the United States have grown relatively slowly in recent years, especially when compared with robot installations in other countries that, like the United States, represent large national markets for industrial robots (see Figure 1). In 2018, China and Japan installed 154,000 and 55,200 industrial robots, respectively, while the United States installed only 40,400 industrial robots.

The Midwest is still an industrial robotics hub in the United States. Key analyses of the geographic distribution of industrial robots show that manufacturing hubs in states in the Midwest and on the Atlantic seaboard, as well as large urban areas in the West and South (e.g., Los Angeles, Houston), experienced the largest increases in robot exposure from 1993 to 2007 (Acemoglu and Restrepo, 2017). Muro, 2017, shows that manufacturing hubs in the Midwest in particular continued to increase their adoption of robots at a quick pace through 2015. In 2007, these hubs had as many as five robots per thousand workers; by 2015, that had increased to as many as 20 or more industrial robots per thousand workers. This number is several times the U.S. average, and it makes the Midwest a geographic area of particular interest in this report.

Automotive, electrical and electronics, metal and machinery, plastic and chemical, food, and other unspecified manufacturing groups demonstrate the largest growth in the adoption of AM robotics worldwide. Of these sectors, electrical and electronics (268 percent), metal and machinery (219 percent), automotive (32 percent), and other unspecified (81 percent) manufacturing groups experienced the fastest growth in the supply of industrial

FIGURE 1

Number of Industrial Robots (Thousands) Installed in 2018 in the Eight Largest National Industrial Robot Markets



SOURCE: IFR, 2019.

robots from 2011 to 2015, respectively (IFR, 2016; Statista, 2020).

Findings: Economic Impacts of Advanced Manufacturing on Firms, Consumers, and Workers

There likely are both economic benefits and adverse consequences to AM. Figure 2 presents a synthesis of our review of the available research on the economic impacts of AM, including advanced automation technologies, such as robotics. The research indicates that there are both clear economic benefits (shown in the green boxes in Figure 2) and potentially adverse consequences (shown in the red boxes) of AM for U.S. firms, consumers, workers, and the broader economy. For example, firms tend to benefit from the adoption of advanced automation technologies via lower labor costs, but such technologies also come with substantial capital investments (for example, see Venkatasamy, 2019). Additionally, the effective use of these technologies in manufacturing requires workers with specialized skills (e.g., basic computer programming), which might increase labor or training costs. Workers' more-specialized skills might drive the higher wages that the employers in AM must pay relative to other manufacturing sectors and the overall economy in recent years (Muro, 2016).

The economic impacts of AM are also mixed for consumers and workers. Similar to process innovations in general, the adoption of AM technologies can be expected to lower quality-adjusted prices of goods over time and to provide more choice for consumers. Workers might also benefit from AM via less repetitive jobs and additional economic rewards for technical skills and higher education (McKinsey Global Institute, 2017).

Some U.S. workers—particularly those with lower levels of education—likely will experience negative effects of AM. As noted earlier, automating portions of the manufacturing process—for instance, using robotics—generally increases productivity per worker and therefore reduces the number of workers required to produce the same quantity of output. These dynamics are most likely to affect less educated workers in the United States. Notably, recent research suggests that negative effects of robotics on employment and wages in the United States over the time period from 1990 to 2007 are real and distinct from alternative explanations, such as the impact of less expensive imports from China and Mexico, offshoring, and the adoption of other computer technologies (Acemoglu and Restrepo, 2019). Research based on data from a variety of European countries similarly demonstrates negative impacts of the introduction of industrial robots on at least some groups of workers

FIGURE 2

The Economic Impact of Advanced Manufacturing

	Firms	Consumers and workers	National economy
+	• Lower labor costs • Shorter lead times • Quicker delivery • Greater range of goods produced • Scalability and economies of scale	• Lower prices and more disposable income • Greater choice of goods • Less repetitive, more-interesting jobs	• Innovation and jobs in robot manufacturing, research and development, marketing, software development • Higher labor productivity with faster economic growth
−	• Need for large capital investment • Long time to update old production technologies • Need for costly, specialized labor	• Potentially less stable employment opportunities, especially for low-skilled and blue-collar workers	• Risk of wealth accumulation to owners of capital • Rising economic inequality

in non-U.S. contexts (Dauth et al., 2018; Graetz and Michaels, 2018; Chiacchio, Petropoulos, and Pichler, 2018; and Bessen et al., 2019). For example, one report notes that the introduction of advanced industrial robots in Germany from 1994 to 2014 did not lead to declines in manufacturing employment for incumbent employees (Dauth et al., 2018). However, the authors observe that the introduction of robots during this period led to lower wage growth among low- to medium-skilled workers and fewer manufacturing jobs for young workers entering the labor market.

New technology, including earlier manufacturing automation, historically has *eventually* produced positive effects in the overall economy—but economic inequality in the United States might increase as a result. Historically, technological innovations and associated shocks to economies have *eventually* produced positive economic effects that outweigh the specific negative effects on displaced workers at the introduction of these new technologies (Autor, 2015). Recent research supports this view in the context of AM, finding a large positive impact on labor productivity from increased use of robotics in production (e.g., Graetz and Michaels, 2018). This pattern is indicative of faster rates of economic growth overall.

Yet research also suggests that following the noted declines in individual wages and employment for some workers under the introduction of other new technologies, a growing supply of industrial robots and automation might lead to increased inequality in wealth and income by increasing the returns to education, technical skills, and capital more broadly (McKinsey Global Institute, 2017).

Given the overall mixed economic impacts of AM, policies to facilitate the positive economic effects of AM and to protect against the negative effects are critical. In any long-term case, governments and/or other stakeholders have a vital role to play in a short- to medium-term response that supports workers in the transition to wider-spread automation in AM (Organisation for Economic Co-operation and Development [OECD], 2017). A weak or absent policy response might unnecessarily aggravate any negative impacts of automation in AM and other industries for less educated and other vulnerable workers. These negative impacts are not without direct costs to employers, governments, and the national economy now and in the future: AM might be unable to draw a sufficiently large and skilled workforce given stigma from previous waves of automation and offshoring in manufacturing (Muro, 2016; Fuchs, 2014).

Existing policy solutions are varied. However, in the remainder of this report, we will focus on an increasingly popular solution: effective education and training programs in AM that prepare technical workers in the United States for a future in which their uniquely human skills, in combination with sophisticated industrial robots, lead to stable jobs and wages sufficient for a middle-income lifestyle while increasing productivity in U.S. AM overall (Council of Economic Advisers, 2019; President's Council of Advisors on Science and Technology, 2011).

The Landscape of Education and Training Programs in Advanced Manufacturing Using Robotics

As the previous section demonstrated, manufacturing in the United States has experienced recent growth, providing new jobs after decades of decline. Yet manufacturing today rarely entails the same processes and machines as the assembly lines that our grandparents might have known; new kinds of skills, such as basic computer programming and dynamic problem-solving, are needed to operate sophisticated industrial robots and other tools used in AM. And although various federal agencies have noted the importance of education and training programs to supply skilled workers, innovate the field, and maintain the overall health of the industry, very little is known about the number and geographic distribution of related education and training programs for these future workers (U.S. Government Accountability Office [GAO] 2019; Fuchs, 2014). Even less is known about the characteristics and content of these programs.

This section begins to fill in these gaps. In the first subsection, we examine the geographic distribution of sub-baccalaureate programs related to manufacturing across the United States. In the second subsection, we look more closely at content in programs available in the Midwest and Pennsylvania—two important centers of manufacturing in the United States that, as noted earlier, have been adopting industrial robots at a faster rate than the United States as a whole.

The Supply of Sub-Baccalaureate Advanced Manufacturing Education Programs

Data and Methods

To map the current landscape of AM training and education programs across the country, we collected and assessed institutional and program-of-study data from the Integrated Postsecondary Education Data System (IPEDS) for all postsecondary institutions for three academic years: 2003–2004, 2009–2010, and 2016–2017.[5] This national picture lays the foundation for a broad overview of the current supply and locations of sub-baccalaureate programs in AM.[6] Although other forms of education and workforce development play a role in expanding the country's AM workforce, data from postsecondary institutions are critical in this study because (1) postsecondary institutions are the major provider of technical workforce training in this country and (2) there are relatively reliable and standardized data on these institutions and their programs over time (Carnevale, Rose, and Hanson, 2012).[7] We further focus on entry-level technical training given the relative dearth of skilled technicians in AM and other industries (Council of Economic Advisers, 2019; National Academies of Sciences, Engineering, and Medicine, 2017a).

Findings

According to IPEDS data, there were 3,883 postsecondary institutions serving U.S. undergraduates as of the 2016–2017 academic year (IPEDS, undated). About 38 percent (1,476) of these institutions were two-year community colleges, and about 62 percent (2,407) were four-year colleges or universities (IPEDS, undated). Overall, the IPEDS shows nearly 4,000 postsecondary institutions offering 271,497 programs spanning 1,412 unique fields of study in the 2016–2017 academic year (IPEDS, undated). Of these unique fields of study, 64 in "engineering/production" and nine in "manufacturing" are potentially related to AM, based on the Classification of Instructional Program (CIP) codes.[8] Given the present focus on skilled technicians in AM, we focus on the nine fields of study included in the "manufacturing" CIP.[9] The shares of programs in this CIP available at different types of postsecondary institutions are shown in Figure 3.

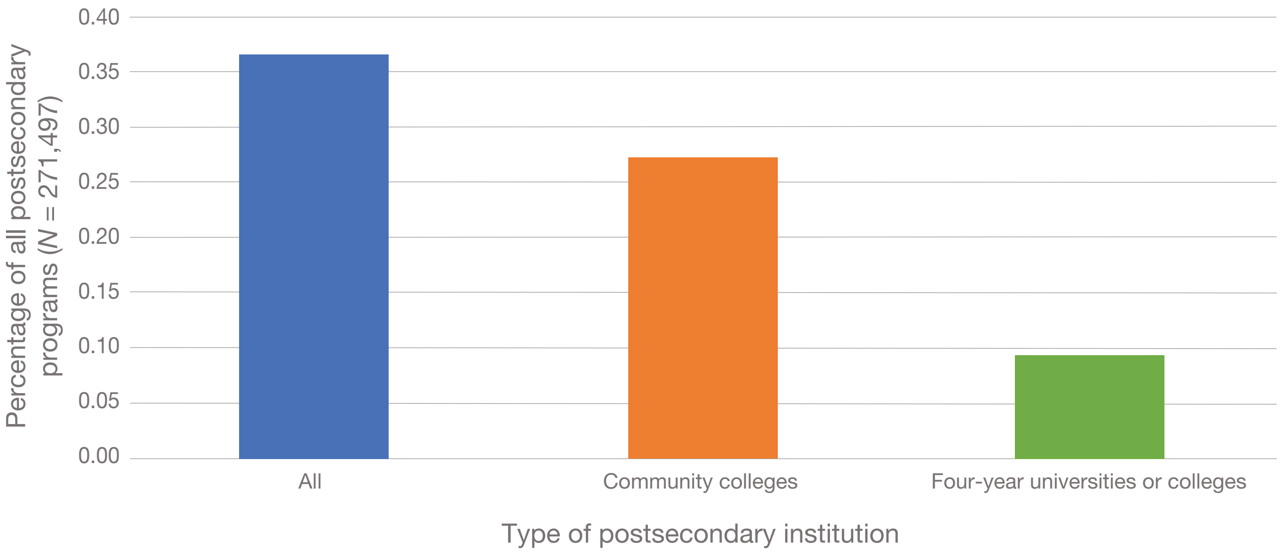
A small share of postsecondary programs in the United States directly addresses manufacturing. A rather small share of the total number of U.S. postsecondary programs (less than 1 percent; n = 994) encompasses the fields of study under the "manufacturing" CIP. Breaking these manufacturing programs down by the type of postsecondary institution, it appears that the bulk of manufacturing programs offered culminates in an associate's degree or lower at the nation's community colleges (n = 743); only about 0.1 percent of all postsecondary programs serving undergraduate students in the United States are directly related to manufacturing and are offered by a four-year institution (n = 251).

The geographic distribution of manufacturing programs follows historical patterns of manufacturing in the United States. Figure 4 shows the number of postsecondary institutions offering a program of study in manufacturing at the sub-baccalaureate level for the 2016–2017 academic year, across the United States. The number of institutions is arrayed by county and adjusted for population size differences across counties (per 10,000 persons 15–64 years of age). Broadly speaking, the map shows that sub-baccalaureate programs related to manufacturing are concentrated around key population centers and throughout the Midwest and the South.[10]

There has been notable growth over time, however, in the number of sub-baccalaureate programs directly related to manufacturing. This growth is demonstrated in two additional heat maps for the academic years 2003–2004 and 2009–2010, using the same metrics as before. Comparing the 2016–2017 map (Figure 4) with maps from these earlier years (Figures 5 and 6), it becomes evident that (1) the adjusted number of programs has increased

FIGURE 3

Percentage of All Programs in "Manufacturing" by Type of Postsecondary Institution, 2016–2017 Academic Year



SOURCE: IPEDS, undated.

NOTE: The two bars on the right side of the figure, which represent the percentage share of postsecondary programs related to manufacturing at community colleges and at four-year universities or colleges, respectively, do not add up to the percentage share shown in the left bar of the figure (all postsecondary programs) because of slight rounding differences.

markedly since the 2003–2004 academic year, and even since the 2009–2010 academic year and the Great Recession, and (2) much of this growth has been concentrated in the Midwest and the South. In the case of the Midwest and contiguous centers of manufacturing in western Pennsylvania, manufacturing programs have become more common. In the case of the South, states with previously low concentrations of sub-baccalaureate manufacturing programs experienced notable growth, especially such states as Tennessee, Kentucky, Louisiana, and Arkansas.

Program Characteristics and Content of Sub-Baccalaureate Education Programs in Advanced Manufacturing with Robotics

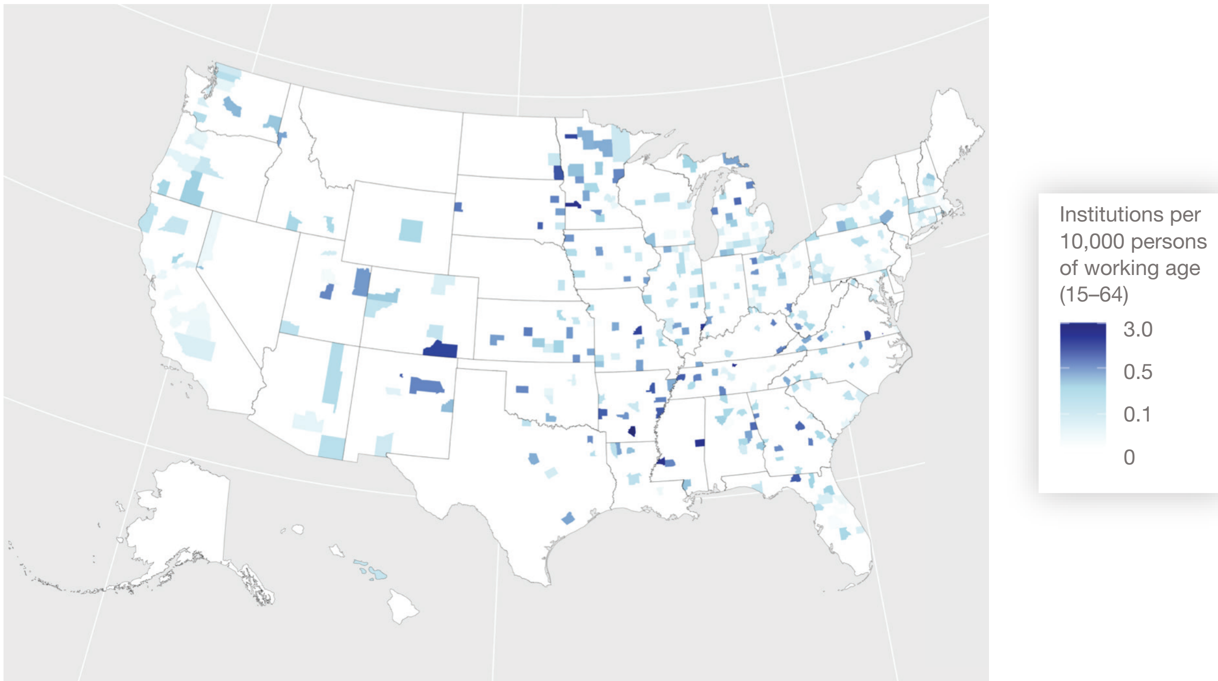
Data and Methods

In this part of the report, we analyze primary data on a subset of AM programs with robotics at the sub-baccalaureate level in the Midwest Census region and Pennsylvania.[11] Using the universe of training programs listed in the CareerOneStop repository from the U.S. Department of Labor's Employment and Training Administration (ETA), we constructed a primary data set describing the characteristics and content of a random 50-percent sample, by state, of programs in AM with robotics in the Midwest and Pennsylvania at the sub-baccalaureate level.[12] A search of the CareerOneStop repository for these states resulted in 1,263 programs located in the Midwest Census region, plus Pennsylvania; a more limited search through these programs using the keyword "robotics" produced a set of 222 programs. Using course syllabi, program descriptions, and other publicly available program information, two coders independently coded a random 50-percent sample of the 222 programs ($N = 111$).

Coding occurred in iterative cycles by state, with a maximum of 20 programs coded per cycle. At the conclusion of the first cycle, the coders met to discuss and resolve incongruences in their coding of the same 20 programs. The coding team updated the coding framework at each cycle using these coding

FIGURE 4

Number of Postsecondary Institutions Offering Sub-Baccalaureate Programs in Manufacturing and Robotics per 10,000 Persons of Working Age (15–64) by U.S. County, 2016–2017 Academic Year



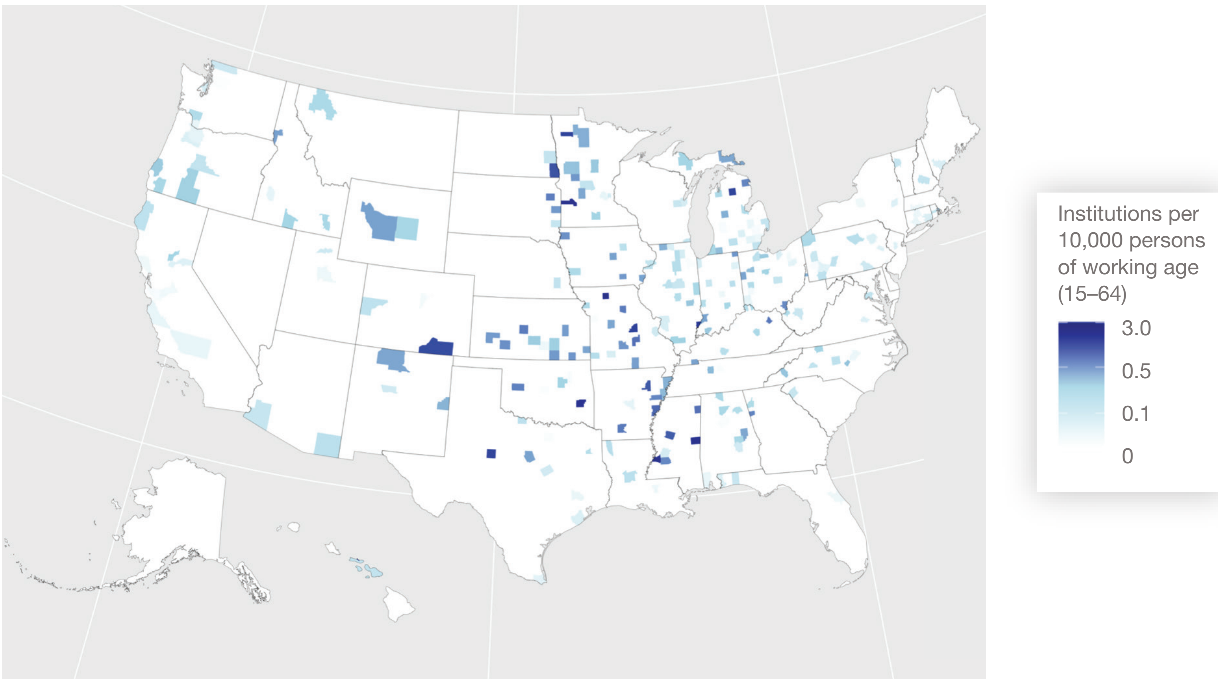
SOURCE: IPEDS, undated.

resolutions and decisions and applied the coding to all programs in the sample. A single trained analyst coded the remaining programs after the first cycle of coding. However, the coding team continued to meet at the end of each coding cycle to discuss the process and collaboratively resolve coding issues that arose.

Program codes included the following: (1) type of terminal credentials (less-than-one-year, one-year, and two-year, or associate's); (2) whether discrete and short-program credentials can be combined sequentially, or "stacked," to satisfy the requirements for a longer-program credential, such as an associate's degree; (3) whether the program notes a specific industry partner; (4) whether the program provides an industry-based credential; (5) alternative modes of instruction other than traditional classroom instruction (online, field- or work-based, bootcamp); and (6) the types of skills emphasized in a given program. Empirical research or industry commentaries suggest that each of these characteristics is important for adult learners' success in AM education and training and more generally (e.g., see Bailey and Belfield, 2017; Belfield and Bailey, 2017; Carnevale, Rose, and Hanson, 2012; Holzer, 2015; Alpert, Couch, and Harmon, 2016; National Association of Manufacturers, 2020; and the section of this report titled "Promising Practices in Education and Training for the Advanced Manufacturing Workforce"). Additionally, the ETA's AM competency model notes important skills that technicians in AM will need to master generally to perform their jobs effectively.[13] These skills include personal effectiveness skills and academic, workplace, and general technical skills. We therefore assessed whether a program emphasized each of these skills and their constituent subskills highlighted by the ETA in its AM competency model. We further categorized the different skills in the ETA's AM competency model according to technical and nontechnical 21st-century skills. According to many experts and policymakers, most workers in the contemporary labor force—including skilled technicians in AM—need

FIGURE 5

Number of Postsecondary Institutions Offering Sub-Baccalaureate Programs in Manufacturing and Robotics per 10,000 Persons of Working Age (15–64) by U.S. County, 2009–2010 Academic Year



SOURCE: IPEDS, undated.

nontechnical skills (National Academies of Sciences, Engineering, and Medicine, 2017a). In fact, the individual wage returns to nonroutine analytic and interpersonal tasks that require these nontechnical skills have markedly increased over the past 50 years; this trend is likely to continue (Liu and Grusky, 2013; Deming, 2017; and Beaudry, Green, and Sand, 2016).

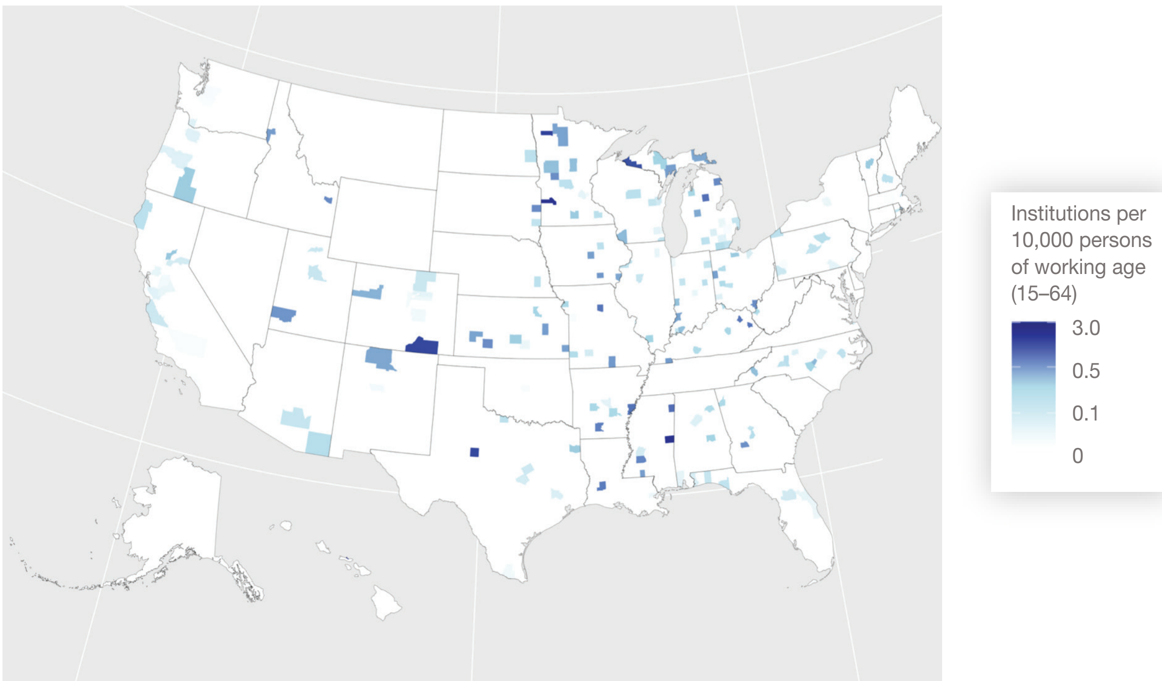
There are obvious caveats to the constructed data. The data are based entirely on publicly available information for a sample of sub-baccalaureate programs. This information is typically intended to promote programs of study to potential students and others, as well as to provide clear and concise information to current students. This publicly available information might omit critical details, such as informal partnerships with industry partners that still inform program content in critical ways or larger programmatic emphases on 21st-century skills threaded throughout a program's technical curriculum. Nonetheless, the constructed data used in our analysis represent a unique first look at what sub-baccalaureate programs in AM with robotics emphasize in their program materials. Importantly, there are no other readily available, standardized data describing sub-baccalaureate programs that provide the degree of detail presented here. In the final section of this report, we make specific recommendations to remedy this data problem.

Findings

Figure 7 shows the percentage of programs from our analytic sample that provide an associate's degree, one-year certificate, and less-than-one-year certificate, respectively. Overall, nearly all programs in the sample offer a two-year associate's degree. About half of these programs publicize at least one certificate in AM with robotics that takes less than an academic year to complete. In contrast to the share of programs publicly offering an associate's degree or a less-than-one-year certificate, only about 20 percent of programs publicize a one-year certificate.

FIGURE 6

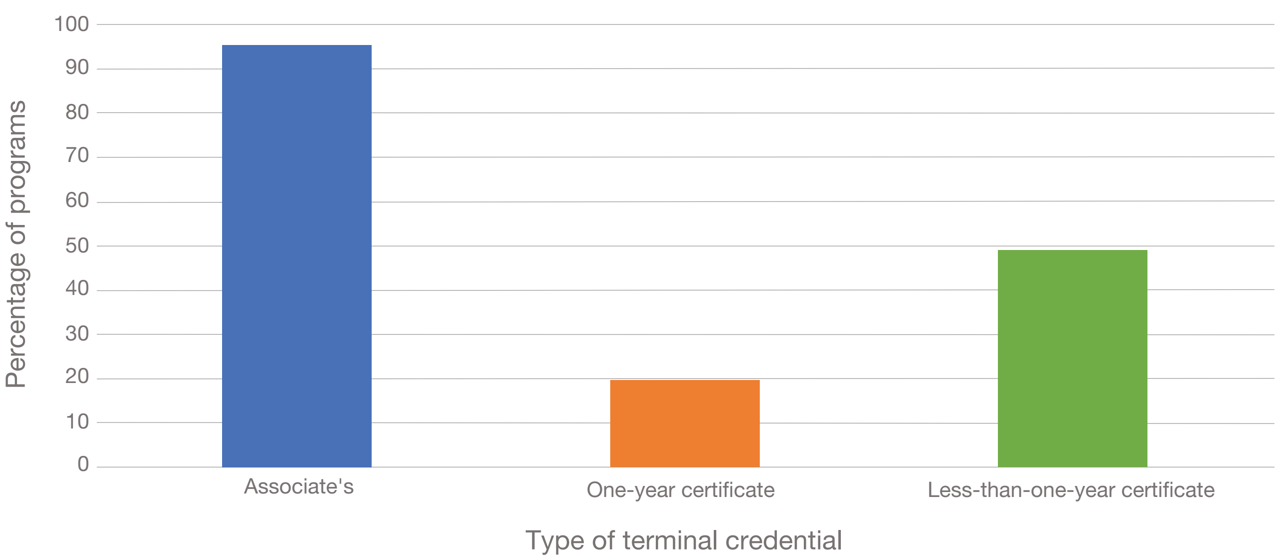
Number of Postsecondary Institutions Offering Sub-Baccalaureate Programs in Manufacturing and Robotics per 10,000 Persons of Working Age (15–64) by U.S. County, 2003–2004 Academic Year



SOURCE: IPEDS, undated.

FIGURE 7

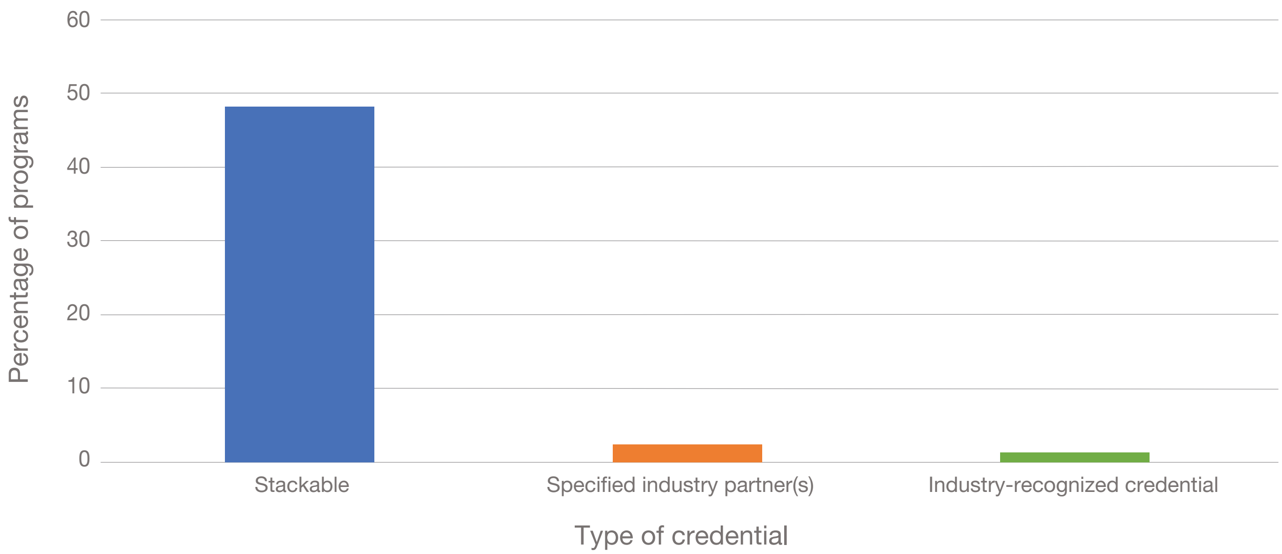
Percentage of Programs Offering Various Terminal Credentials, Midwest and Pennsylvania, 2019



SOURCE: CareerOneStop, undated.

FIGURE 8

Percentage of Programs Offering Stackable or Industry-Related Credentials, Midwest and Pennsylvania, 2019



SOURCE: CareerOneStop, undated.

AM with robotics programs vary in how credentials are combined and industry ties for the certificates that are offered. Figure 8 shows the percentage of programs in our sample that publicize (1) at least one credential that can be stacked toward a higher certificate or degree, (2) at least one credential offered in tandem with an industry partner, and/or (3) at least one industry-recognized credential.

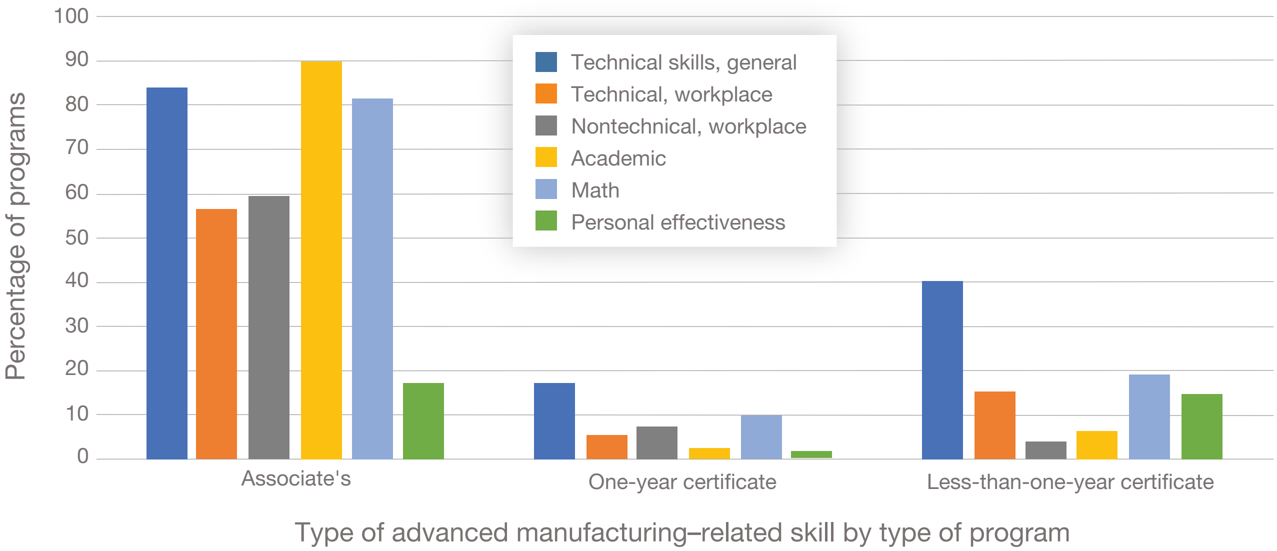
The percentage share of programs offering stackable credentials in our sample is shown in the left-hand bar in Figure 8. Some industry experts suggest that stackable credentials offer necessary flexibility for developing and growing a skilled AM workforce (e.g., National Association of Manufacturers, 2020; see the section of this report on promising practices in AM education and training). Similar to short-term credentials that take less than a year to complete, about half of programs in AM with robotics allow students to stack credentials toward a higher certificate or degree. It seems, overall, that sub-baccalaureate programs in AM with robotics tend to prioritize timely and flexible training. This tracks stakeholder sentiments concerning acute training needs in AM and other fields (National Academies of Sciences, Engineering, and Medicine, 2017a; National Academies of Sciences, Engineering, and Medicine, 2017b).

However, publicly available information from program websites indicates that sub-baccalaureate programs in the Midwest states and Pennsylvania might struggle to establish specific industry partnerships and/or offer industry-recognized credentials: Fewer than 5 percent of programs publicize specific industry partners or industry-recognized credentials as part of their curriculum. Almost certainly, many of these programs have industry connections of some kind. Still, they do not name a specific industry partner. This finding aligns with a variety of sources calling for more and deeper connections between community college training programs and industry (National Academies of Sciences, Engineering, and Medicine, 2017a). The omission of specified industry-recognized credentials in our sample of programs might be due to a lack of widely recognized industry-based credentials in robotics technician training. It is also possible that these programs simply do not publicize such information on their program websites.

Most programs emphasize technical and academic skills but emphasize nontechnical workplace and personal effectiveness skills less. Our analysis of

FIGURE 9

Percentage of Programs Emphasizing Various Advanced Manufacturing–Related Skills, Midwest and Pennsylvania, 2019



SOURCE: CareerOneStop, undated.

programs in the Midwest region and Pennsylvania is illustrated in Figure 9. Skill categories are mutually exclusive and were taken directly from the U.S. Department of Labor's AM competency model and associated category definitions. For example, the category "Technical skills, general" indicates general technical skills, such as manufacturing process and design, that constitute industry-wide technical competencies. Workplace skills in the ETA's AM competency model are broken into two, mutually exclusive categories. "Technical, workplace" indicates skills that involve working with tools and technologies and other technical skills required in manufacturing generally. The category "Nontechnical, workplace" indicates skills, such as "adaptability" and "flexibility" and "teamwork," that are general workplace skills but that do not require technical knowledge of tools and technologies (U.S. Department of Labor, Employment and Training Administration, 2010). Similarly, we separately categorize general, non-math academic skills under "Academic" and math skills under "Math." This is because many sub-baccalaureate AM programs in the sample might emphasize math in their publicized curriculum but omit other academic skills. Separating the two types of workforce skills and the two types of academic skills provides a more nuanced understanding of programs' curricular content.[14]

Figure 9 shows that most programs emphasize technical skills—general and/or those pertaining to the workplace—over other skills. Programs also tend to emphasize academic skills in their publicized program curricula (both math and non-math) over other skills. However, associate's degree programs emphasize overall academic skills (approximately 90 percent) and math skills (approximately 82 percent) at a much higher proportion than do shorter-term credentialing programs.[15] Among one-year and less-than-one-year credential options, a greater emphasis is placed on math specifically—a result presumably driven by the short length of these programs and the need to emphasize directly relevant academic skills.

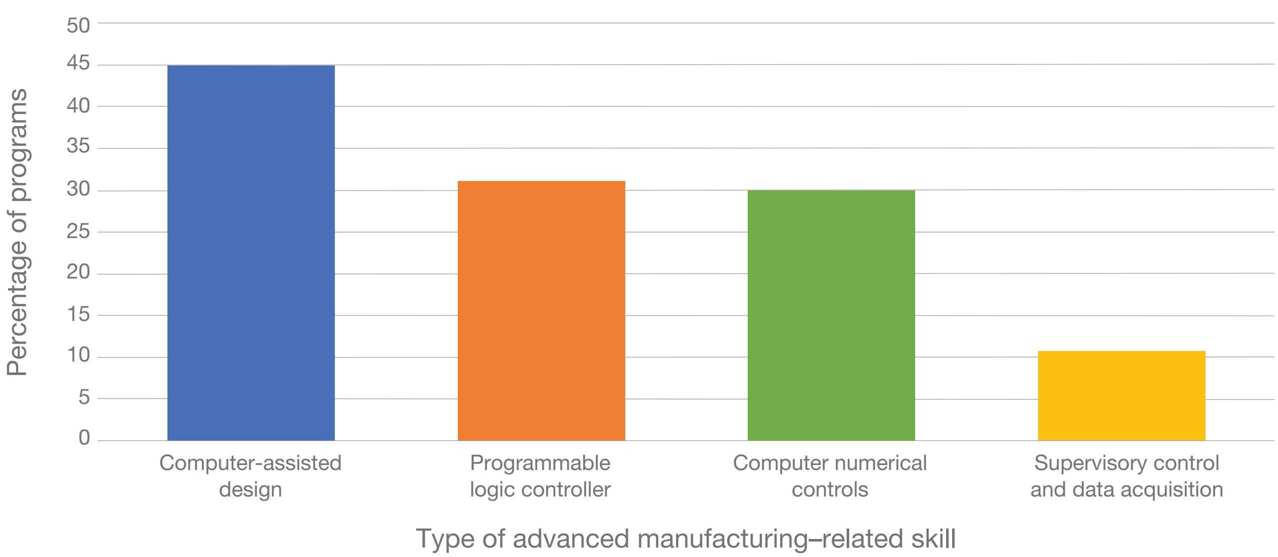
Despite employers' emphasis on nontechnical skills, and despite empirical research noting the growing importance of such skills, programs tend not to publicly emphasize nontechnical skills, including nontechnical workplace skills, such as problem-solving, and personal effectiveness skills, such as communication. This is the case for both two-year and less-than-two-year programs in our sample. Figure 9 shows that about 85 and 57 percent of two-year programs emphasize general technical skills and technical workplace skills in their public program curricula, respectively. Yet only about 18 percent of two-year programs emphasize personal effectiveness skills. Even smaller shares of one-year and less-than-one-year credential programs publicly emphasize personal effectiveness skills (approximately 3 percent and approximately 14 percent, respectively). It seems, then, that the flexibility offered by shorter-term credential programs might come at the cost of nontechnical skills that employers and others consider critical for the AM workforce.

Many programs do not emphasize some of the specific technical skills that an AM technician will need to perform. Given the coding methods described in the previous section, we further distinguish different technical skills required for AM technicians as specified in the Occupational Information Network (O*NET) system, including computer-assisted design, programmable logic controllers, computer numerical controls, and supervisory control and data acquisition.[16] Figure 10 shows that a significant minority of programs emphasize technical skills related to computer-assisted design (45 percent), programmable logic controllers (31 percent), and computer numerical controls (30 percent) in the publicly available materials describing their programs and curricula. Very few programs publicly emphasize supervisory control and data acquisition (12 percent).

Work-based learning is popular in workforce development but does not appear to have taken root in AM programs in the Midwest and Pennsylvania. Today, it remains the case that most instruction in a postsecondary education or training program occurs in a relatively traditional classroom setting with an expert instructor, whether the classroom is a lecture hall or a technology center's shop floor. For example, Figure 11 shows that a rather small percentage of sub-baccalaureate AM with robotics programs in our sample provided either online courses or field experiences (such as longer-term apprenticeships or other, shorter work-based learning) at the associate's degree or one-year certificate levels. Less-than-one-year programs offered neither online courses nor field experiences. Regardless of the terminal credential, none of the programs in our sample publicly emphasized bootcamps as part of their program (but see the description of the Michigan Coalition for Advanced Manufacturing's program in the section of the report on promising practices in AM education

FIGURE 10

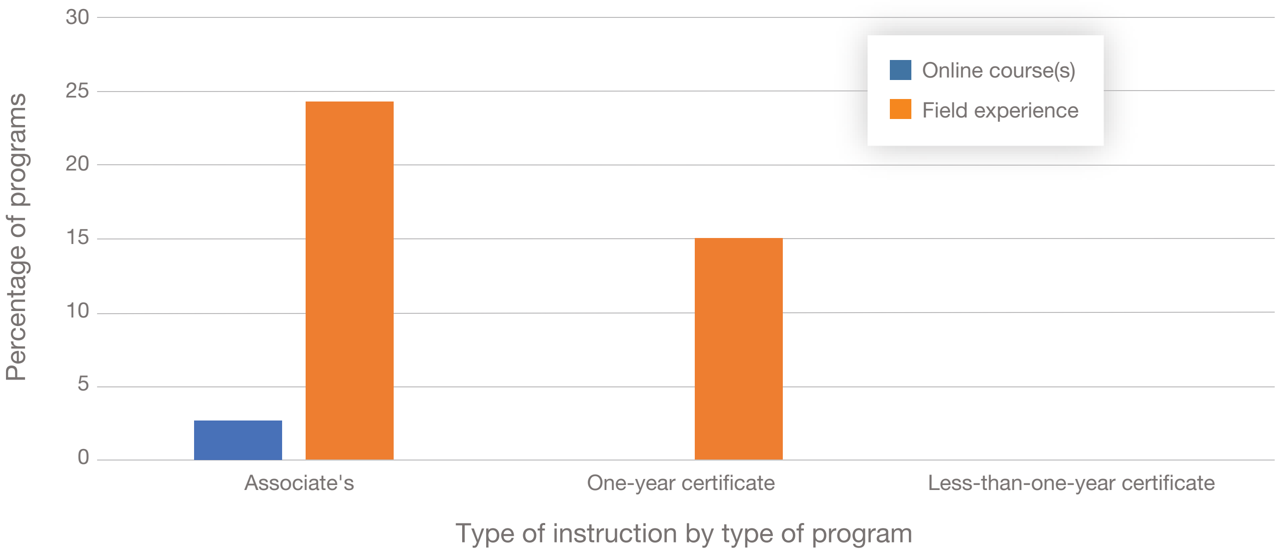
Percentage of Programs Emphasizing Technical Advanced Manufacturing–Related Skills Specified in the Occupational Information Network System, Midwest and Pennsylvania, 2019



SOURCE: CareerOneStop, undated.

FIGURE 11

Percentage of Programs Offering Online Course(s) or a Field Experience, Midwest and Pennsylvania, 2019



SOURCE: CareerOneStop, undated.

and training). Although it is perhaps unsurprising that AM with robotics programs that typically enroll a smaller number of students in courses with intensive and variable curricula do not use online courses or bootcamps more generally in their programs, it is somewhat surprising that field experiences are emphasized so little. Field experiences have been an integral part of education and training in many trades for quite some time (Holzer, 2015), and the Manufacturing Institute (National Association of Manufacturers, undated) recently endorsed apprenticeships and other field experiences as integral to effective training in AM.

Overall, this section provides a portrait of sub-baccalaureate programs in AM with robotics across the Midwest and in Pennsylvania, key centers of U.S. manufacturing. Most programs provide a wide array of credentials (often stackable) and emphasize technical skills. However, many of the programs do not offer field experience to students or provide direct training in 21st-century skills, such as initiative and problem-solving. Most programs also do not emphasize strong partnerships with specific industry partners in their publicly available program materials—perhaps indicative of missing or inchoate postsecondary-industry collaboration in AM training. This overview of the landscape of sub-baccalaureate programs in AM with robotics provides an important first look at a significant segment of education and training programs in AM. But by no means is this overview meant to be a last look. Additional data and analyses are critical to enhance understanding of the supply of education and training programs in AM and the future AM workforce that they produce. This is especially the case given (1) the growing number of technical education and training providers in higher education and otherwise and (2) the projected growth in the installation of advanced robots in manufacturing in the United States and worldwide (see Figure 1; Burrowes et al., 2014).

Promising Practices in Education and Training for the Advanced Manufacturing Workforce

The previous section established a portrait of sub-baccalaureate programs in AM with robotics across the Midwest and in Pennsylvania. But given the noted growth of advanced robot installations in

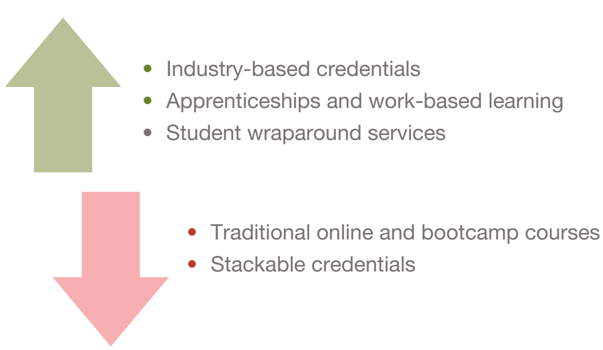
U.S. manufacturing and a push to increase automation in manufacturing with advanced industrial robots worldwide, should these programs—or AM programs more generally—be updated? And if so, in what ways? To understand how AM programs should be shaped to maintain U.S. prominence in manufacturing and to benefit program participants, we examined the available research evaluating best practices in education, AM training, and, more specifically, AM training programs with robotics. To date, there is scant information relevant to the latter two areas. Although we were unable to determine best practices in education and training in AM with robotics given the little available research, we were able to determine which educational practices point the way forward in shaping new programs and strengthening those that exist. Identification of these promising practices is critical for evidence-based decisionmaking in skilled technical workforce development overall and in AM with robotics specifically (National Science and Technology Council, Subcommittee on Advanced Manufacturing, Committee on Technology, 2018).

Data and Methods

Our literature review focuses on isolating experimental and quasi-experimental research on the effects of discrete instructional and other practices in education and training programs in AM at the sub-baccalaureate level (Hart, 2018; Booth, Sutton, and Papaioannou, 2016). The findings presented in the following subsection are based on our synthesis of this research and our assessment of the rigor of evidence in this research given the What Works Clearinghouse (WWC) guidelines.[17] WWC guidelines emphasize a subset of highly reliable experimental and quasi-experimental research designs (e.g., randomized control field trials, regression discontinuity, and continuous interrupted time series) that research demonstrates provide the best estimates of the causal effects of a given education intervention on outcomes of interest. Figure 12 provides a visual summary of the findings from our review of the literature on promising practices in postsecondary education.

FIGURE 12

Promising Practices in Postsecondary Education, Summary



NOTE: The green arrow indicates more-promising forms of training given the available research evidence; the pink arrow indicates less promising forms of training given the available research evidence.

Findings

Types of Credentialing: Industry-Based and Stackable

Industry-based credentials in growing industries and sectors can increase program participants' earnings—though publicly available information for AM sub-baccalaureate programs often does not indicate that such credentials are offered. In 2014, the U.S. Department of Labor emphasized that industry-based credentials—that is, postsecondary credentials recognized by key agencies in the industry that the program focuses on—can ultimately bring about better earnings for participants in growing job sectors after they finish relevant programs. Other research generally validates these findings. For example, Jepsen, Troske, and Coomes, 2014, provides an evaluation of the labor market wage returns to Kentucky students of a variety of sub-baccalaureate credentials, including two-year associate's degrees and shorter-term certificates. The authors report returns of $1,500 to $2,000 in quarterly earnings for a two-year degree, and shorter-term certificates garnered approximately $300 in quarterly earnings. Credentials in health and technical fields led to even higher returns, suggesting that education or training directly related to growing industries and sectors benefits students more. Other analyses for community college students in Ohio, Washington state, California, Virginia, and North Carolina similarly find larger returns for two-year degrees, but still-notable returns for certificates, as well as larger returns for credentials in health and key applied technical fields (Bettinger et al., 2015; Dadgar and Trimble, 2015; Stevens, Kurlaender, and Grosz, 2018; and Xu and Trimble, 2016).

Increases in individual wages given the completion of a sub-baccalaureate credential, particularly in the case of credentials in health or technical fields, can accumulate over the labor market career. Recent research suggests that U.S. workers who receive sub-baccalaureate career or technical credentials can earn about 8 to 9 percent more than high school graduates in the 20 years following high school graduation. Still, observed cumulative wage differences between those who receive career or technical sub-baccalaureate credentials and those who receive high school credentials are smaller than the wage differences observed between U.S. workers who complete a four-year bachelor's degree and U.S. workers who complete a high school credential or even who attend significant amounts of college without completing any credential (Kim and Tamborini, 2019). It is also not clear whether sub-baccalaureate career or technical credentials provide as much economic security as a college education under technological shocks—such as a growing wave of automation in a nation's economy. Research on European labor markets indicates that workers with applied technical training experience higher rates of unemployment under such shocks; unemployment might be associated with long-term wage losses even after an individual finds new employment (Hanushek et al., 2017). This is not to say that a college education is necessary for economic security across the life cycle. The evidence does indicate, however, that the question of long-term returns to sub-baccalaureate career or technical credentials, especially under changing economic conditions, merits further consideration.

Much of the research on individual wage returns of career and technical sub-baccalaureate credentials meets the U.S. Department of Education's WWC standards. However, it remains unclear what the specific effects of industry-based credentials in AM might be. Overall, more research using rigorous experimental or quasi-experimental techniques is necessary to definitively say whether industry-based credentials specifically benefit U.S. workers in AM and thus represent a best practice in education and training in AM. However, it is worth noting that despite the promising evidence vis-à-vis industry-based credentials, only a relatively small share of sub-baccalaureate programs in AM in the Midwest and Pennsylvania may provide such credentials (see Figure 8).

It is unclear whether stackable credentials benefit participants in AM programs or their educational institutions. A 2014 report by the U.S. Department of Labor, U.S. Department of Commerce, U.S. Department of Education, and U.S. Department of Health and Human Services also notes the importance of flexible education and training for individuals; education stakeholders have responded by increasingly emphasizing microcredentials that can be completed in relatively little time and that can be combined, or stacked, to attain a higher certificate or degree. However, only some community colleges and programs emphasize stackable credentials (about 15 percent of California community colleges and about half of sub-baccalaureate programs in AM with robotics at community colleges in the Midwest and Pennsylvania; see Bohn et al., 2018, and the section of this report titled "The Landscape of Education and Training Programs in Advanced Manufacturing Using Robotics"). Additionally, a still smaller share of U.S. postsecondary students (3 to 5 percent) earn stackable credentials (Bailey and Belfield, 2017).

A search of existing research produced few studies that evaluate the effects of stackable credentials on students ($N = 3$). Of these studies, the majority conclude that stackable credentials might induce students to subsequently attain more postsecondary credits and even additional certifications (Giani and Fox, 2017; Bohn et al., 2018). Compared with a single earned credential, stacked credentials are not associated with notable individual wage increases—but they are not associated with decreases, either (Bailey and Belfield, 2017). However, some groups of students, such as those from racial and ethnic minority backgrounds, might not benefit from stackable credentials at all (Giani and Fox, 2017; Bohn et al., 2018).

None of this research provides rigorous evidence on the effects of stackable credentials according to the WWC guidelines. Given the uneven findings and overall quality of research, it is difficult, if not impossible, to say whether stackable credentials represent a clear best practice in education and training in AM, much less in education and training in AM with robotics.

Modes of Instruction: Online Courses, Bootcamps, and Apprenticeships

Experts have flagged online instruction, bootcamp courses, and apprenticeships as potential solutions to standing up a skilled workforce in AM and in other fields (e.g., see Spak, 2013; Hamori, 2018; Gan, 2015; Kinder, 2018; and Goolsbee, Hubbard, and Ganz, 2019). Although the research evidence for these solutions is often thin, especially for bootcamps and apprenticeships, it is worth compiling the findings here to understand how these modes of instruction might or might not positively affect AM student outcomes.

Research shows that traditional online instruction has negative outcomes. Research on the potential effects of online courses, particularly massive open online courses (MOOCs), stretches back for years. Overall, about one-third of undergraduate students will take at least one online course during their postsecondary education, and online courses, MOOCs or otherwise, have rapidly grown three- to fourfold from about 2010 through the present (Chuang and Ho, 2017). Student completion and certification rates in these courses have not kept pace with enrollments, however. The average completion rate among online courses generally is only about 10 percent (Fidalgo-Blanco, Sein-Echaluce, and García-Peñalvo, 2016). Among participating HarvardX and MITx students who attended a MOOC in the period from fall 2012 through summer 2016 and who expressed an intention to complete enough courses to earn a certification (N = 489,000), about 30 percent earned a certification (Chuang and Ho, 2017).[18] This is compared with about 40 percent of first-time undergraduate students enrolled in a community college who earn a credential of some kind within six years of initial enrollment (Shapiro et al., 2018).

Overall, the available research on the student impacts of online education is relatively rigorous. These studies mainly employ randomized control trials, regression discontinuity, and other research designs that meet some of the highest WWC standards for isolating a causal effect of the educational intervention of interest. The most-rigorous research indicates that, although (massive open) online courses might increase access to postsecondary education among some student populations (e.g., midcareer professionals interested in obtaining a master's degree; Goodman, Melkers, and Pallais, 2017), most students—especially academically weak, community college, and for-profit college students—perform worse in online courses overall (Joyce et al., 2015; Alpert, Couch, and Harmon, 2016; Bettinger et al., 2015). There is potentially one important qualification to this characterization of the negative impacts of online courses on students, however. After randomly assigning undergraduate students at a four-year institution to a large, in-person course or a MOOC, two studies found that once in-person courses become large enough, there is no detectable difference in student impacts between a MOOC and an in-person course (Figlio, Rush, and Yin, 2013; Alpert, Couch, and Harmon, 2016).

However, innovations in online instruction might make this form of education and training more effective. Although large or other online courses generally have negative effects on students, recent studies have found that students randomized to a blended course that combines some in-person instruction with some online instruction performed as well as students randomized to a traditional, in-person-only course. In contrast, students randomized to a fully online course performed about half a letter grade worse than students in the same study who attended a blended or traditional course (Alpert, Couch, and Harmon, 2016; see also Bowen et al., 2014; and Joyce et al., 2015). Moreover, some scholars suggest that online courses with social and cooperative elements among students enhance student learning (e.g., Fidalgo-Blanco, Sein-Echaluce, and García-Peñalvo, 2016), but research on these aspects of online courses is limited and preliminary.

Overall, the available research evaluating the effects of online courses and especially MOOCs focuses on academic subjects of study with traditional undergraduate- and graduate-level students.

None of the research on traditional and newer forms of online instruction evaluates online instruction in the context of career and technical education (CTE) in general, including AM with robotics. This is the state of the research, even as AM stakeholders advocate for online training and education (e.g., see Spak, 2013) and manufacturing firms implement their own online training (National Academies of Sciences, Engineering, and Medicine, 2017a).

Training bootcamps are growing in number in postsecondary education and workforce development, but their effectiveness is unclear. Bootcamp courses aim to develop student competency in key technical skills in a few days to a few months, and they are often seen as a means to "future proof" workforce skills in the face of rapid technological innovation. These bootcamps tend to emphasize experiential and project-based learning and adapt a general curriculum to local industry needs (Mulas et al., 2017). The number of bootcamps, particularly coding bootcamps, appears to have grown rapidly in recent years; in 2011, fewer than 100 members on LinkedIn indicated that they had completed a bootcamp, but by 2014, about 8,000 members indicated they had completed a coding bootcamp—and in the first half of 2015, the number of members indicating completion of a bootcamp was even greater than that (Gan, 2015). This growth is likely to continue. The U.S. Department of Education recently extended coverage of federal education loans to some bootcamps, as did the U.S. Congress, under the Forever GI Bill (Anderson, 2015; Fain, 2018; Pub. L. 115-48, 2017).

Some postsecondary institutions and organizations are already offering traditional-format bootcamps in AM (e.g., the Carnegie Mellon Robotics Academy's Smart Manufacturing and Advanced Robotics Training—Extended Reach [SMART-ER] program and the University of Pittsburgh's Manufacturing Assistance Center [MAC]).[19] Other AM programs have begun to use bootcamps as part of a blended model with bootcamp prerequisites that must be completed prior to beginning the full program (e.g., the Michigan Coalition for Advanced Manufacturing; Lewis-Charp et al., 2017), and blended bootcamp–traditional instruction models are increasingly common in postsecondary education more generally (Fain, 2018).

Despite notable growth in bootcamp offerings in the past decade, our review found no research that evaluates the effects of a bootcamp course on student outcomes and meets the WWC standards for rigorous causal research. Several descriptive studies compare observationally similar students from the same student population, however, and suggest that bootcamp courses have limited benefits for students. For example, Feldon et al., 2017, evaluated the benefits of a summer bootcamp on statistics and research for graduate students in the life sciences attending different institutions across the United States (294 students, 53 institutions). The authors reported no statistically significant association between bootcamp attendance and students' skill development, socialization into the academic community, or scholarly productivity. The dire need for rigorous research on bootcamp courses generally is noted elsewhere (Mulas et al., 2017; Fain, 2018). We echo that sentiment here and in the specific case of AM, especially given the introduction of blended bootcamp–traditional instruction models in AM.

Apprenticeships are increasing, and a small number of studies suggests that they might be effective. Apprenticeships are formal workplace-based training models that aim to develop worker skills while on the job and are of increasing interest to educators and employers alike (Goolsbee, Hubbard, and Ganz, 2019). Along those lines, the federal government and some state governments recently enacted legislation aimed at increasing apprenticeships and other work-based learning (e.g., the Strengthening Career and Technical Education for the 21st Century Act; see the National Science and Technology Council, Committee on STEM Education, 2018).

Yet only 0.03 percent of U.S. workers are currently in an apprenticeship (Goolsbee, Hubbard, and Ganz, 2019). Partly as a result, rigorous research on the effects of apprenticeships on individual outcomes is still developing (Rosen, Visher, and Beal, 2018; Council of Economic Advisers, 2019). A single study of Registered Apprenticeship Programs with the U.S. Department of Labor, spanning ten states, suggests that an apprenticeship increases individual earnings by about $240,037 over an individual's lifetime (Reed et al., 2012). However, this study compared individuals who self-selected into apprenticeship programs with observationally similar individuals who did not. According to WWC standards, this research provides insufficient evidence as to the effects of adult apprenticeship programs on apprentice outcomes. Research on Career Academies at the K–12 level using an experimental design suggests that programs that include significant work-based learning can markedly improve student labor market outcomes. Students who attended a Career Academy earned $2,088 more per year for a total of an additional $16,704 in earnings over an eight-year period (Kemple, 2008). Although this research is based on a randomized control trial, others note that it is often unclear whether students received work-based learning opportunities alone or in tandem with other learning opportunities, because of important differences across Career Academy schools (Lerman and Packer, 2015). It is therefore difficult to say whether it is the apprenticeship-style approach or some other feature of Career Academies that leads to increased student earnings.

While a very small share of U.S. workers currently are in an apprenticeship, this form of work-based learning is far more common in other countries, such as Germany and Austria. Novella and Pérez-Dávila, 2017, provides an extensive review of the international literature evaluating the effects of apprenticeships on individual, employer, and other outcomes and notes just three or four experimental and quasi-experimental studies in a handful of countries (Germany, Brazil, Italy, and Romania).[20] Overall, those studies indicate that the effects of an apprenticeship for the apprentice are generally positive—but quite variable. For example, the predicted probability of employment upon completion of an apprenticeship ranges from an increase of 7 percent in Brazil to 0 percent in Romania. In the case of wages, an individual might expect as much as a 14-percent increase in lifetime wages, given an apprenticeship; but rigorous research also indicates a 0-percent increase (Novella and Pérez-Dávila, 2017).

Considering all of the evidence related to apprenticeships, the OECD, 2018, highlights practices that help ensure an effective apprenticeship system that educates and prepares students for rewarding jobs while meeting employer demands for skilled labor. These practices include labor market policies ensuring that apprenticeship duration and wages respond to costs and benefits incurred by both the apprentice and the employer as an apprentice becomes more skilled under an employer's tutelage, fair competition between apprenticeships and other forms of education and training (e.g., equal government subsidies for different forms of education), avoidance of universal subsidies aimed at employers to increase apprenticeships, a focus on funding policies to increase apprentices' rate of learning and skill development, policies to improve employer-provided training and administrative costs, shortening of the duration of an apprenticeship and provision of greater supports for vulnerable populations, and placement of an apprentice in a skilled occupation.

Informational and Behavioral Supports for Student Success

Informational and behavioral supports are important to the success of nontraditional and disadvantaged students. Many AM stakeholders emphasize these student populations in their programs (e.g., Carnegie Mellon Robotics Academy's SMART-ER program). There are essentially three kinds of supports that postsecondary students might need to successfully complete an education or training program: financial, academic or instructional, and informational and behavioral (Long and Riley, 2007; Page and Scott-Clayton, 2016). Traditionally, postsecondary support programs have emphasized financial or academic supports. However, the wide variety of supports that make up the informational and behavioral support categories proves critically important for nontraditional and disadvantaged postsecondary students (e.g., Radford, 2013). Such supports often are referred to as "wraparound" supports and include college-going counseling and information, developmental or remedial education, and nonacademic supports, such as transportation and childcare. Experts have flagged these supports as best, "first-dollar" or primary and direct supports that education providers should offer their students (Goolsbee, Hubbard, and Ganz, 2019).

A small number of recent programs aim to provide the full array of supports (financial, academic, and informational and behavioral) to low-income postsecondary students who often face more barriers to postsecondary education and training than other groups. Research evaluating these programs, based on rigorous randomized control trial designs, suggests that such supports can be particularly effective. For example, Scrivener and colleagues evaluated the Accelerated Study in Associate Programs (ASAP) at the City University of New York (CUNY). The ASAP accepts students who need one to two developmental (sometimes referred to as "remedial") courses to earn associate's degrees within three years, and it provides a comprehensive array of financial, academic, and personal supports, including comprehensive and personalized advisement, career counseling, tutoring, waivers for tuition and mandatory fees, public transportation, and additional financial assistance to defray the cost of textbooks.[21] The authors find that the ASAP increased full-time enrollment by 11 percent and semester-to-semester persistence by 10 percent (Scrivener et al., 2012). Importantly, ASAP almost doubled graduation rates of students who needed some developmental education (Scrivener et al., 2015). Similar to ASAP, the One Million Degrees program in Chicago provides holistic supports for community college students, including last-dollar scholarships, skill-building workshops, advising, and coaching. Under a randomized control trial design, the authors report similarly positive effects of the One Million Degrees program on enrollment and persistence (Bertrand et al., 2019).

Overall, extant research indicates that some, but not all, of the practices promoted by manufacturing experts and stakeholders as solutions for the AM workforce are promising. However, much of the research evaluating these practices fails to meet the U.S. Department of Education's WWC guidelines for rigorous experimental and quasi-experimental research. Additionally, little of this research evaluates select educational practices in the context of adult CTE, even though experts suggest that many of these practices are critical for nontraditional postsecondary students who often participate in CTE. None of this research evaluates these practices in the context of AM CTE. Again, this is in spite of the fact that AM and other experts have flagged these practices as key ways to grow a skilled AM workforce. The final section of this report addresses this and other considerations in a set of policy recommendations tailored to AM and based on the research and analyses presented in the preceding sections of this report.

Conclusion and Recommendations

Overall, jobs in AM likely will have greater skill requirements in the near future and beyond, partly because of the adoption and diffusion of newer industrial robotics in manufacturing processes. However, jobs in AM also will likely continue to offer security and relatively high wages (National Academies of Sciences, Engineering, and Medicine, 2017b; National Academies of Sciences, Engineering, and Medicine, 2017a). For U.S. workers and the nation overall to take advantage of these jobs and related economic benefits (e.g., increases in national productivity), stakeholders must lay the foundation now for a robust policy response.

Using existing research and the original analyses presented in this report, we make several specific recommendations for improving education and training in AM. We make these recommendations to industry, government, and training stakeholders—all of whom are necessary to execute these recommendations successfully. For example, although government can fund a detailed needs assessment for a skilled AM workforce, all stakeholders will need to provide detailed data to support this assessment. At present, much of these data are spread across stakeholders and therefore not readily accessible, so a multisector effort is necessary to address this data shortcoming. Our overall analyses and associated recommendations are summarized in Figure 13.

Assess *in detail* the need for a skilled AM with robotics workforce, based on a given AM labor market overall, to plan for and promote AM jobs accordingly. To date, no such assessment is available.[22] We recommend, based on the analysis presented in the section on economic context of education and training in AM with robotics, that future research conduct a detailed needs assessment of the AM workforce in the United States, with an emphasis on robotics—nationally and subnationally

FIGURE 13

Recommendations for Improving Education and Training Programs for Advanced Manufacturing Workforce Development

Findings

- The increasing adoption of advanced industrial robots will have mixed economic impacts but is likely to negatively affect less educated workers in the short to medium term because of a skills gap.
- Sub-baccalaureate programs in AM do not necessarily emphasize critical nontechnical and even some critical technical skills.
- Work-based learning is popular in workforce development and likely improves learning and other student outcomes—but, based on RAND data, it does not appear to have taken root in AM programs.
- Evaluation research on practices in AM education and training is too weak to draw strong conclusions, though some insights can be drawn from existing postsecondary and CTE research.
- Promising educational practices likely include industry-based credentials, apprenticeships, and student wraparound support services.

Recommendations

- Detailed workforce development data, including employer data and data on training program content, are acutely needed to make informed policy decisions to support an AM workforce.
- Detailed needs assessments for AM at the national and local levels, based on varying conditions, are acutely needed to make informed policy decisions to support an AM workforce.
- Rigorous evaluation of practices in AM education and training—especially practices that likely enable agile and responsive workforce development (e.g., threading nontechnical skills through technical courses, industry-based credentials)—is needed.
- Intermediary organizations should be brought to the table more, to bring small to medium-sized employers to the table more.

and for a given industry. This needs assessment should consider varying assumptions about factors related to AM workforce needs, including (1) the global and local supply of industrial robots, (2) the rate of technological innovation in industrial robots, (3) total employer costs of industrial robots, (4) the rate of employer adoption of these robots, (5) the current and projected skilled workforce, (6) the ratio of local human labor costs to global human labor costs, and more. This assessment should carefully evaluate AM workforce needs under various national and global economic conditions, given the sensitivity of manufacturing to economic conditions more generally.[23] This is a particularly important consideration in the context of a "roboticizing" world with integrated supply chains and labor and consumer markets.

Work with all stakeholders to collect quality data for a robust, data-driven workforce development system. Overall, we strongly agree with others who note the critical need for better and more-integrated workforce data systems that support rigorous research for data-driven decisionmaking. Although there are some relevant federal and state data available, they are often insufficiently detailed to support a detailed needs assessment like the one described in the preceding paragraph (National Academies of Sciences, Engineering, and Medicine, 2017a). More-detailed employer and other data have been a long-standing need in the United States (GAO, 2005; GAO, 2019). Not incidentally, such data would also go a long way in helping build the talent pipeline data systems that are advocated by the federal government, the U.S. Chamber of Commerce, and others (Ennis, 2008; Tyszko, Sheets, and Fuller, 2014), and that are presently used in other OECD countries to help manage labor supply and demand for AM and other fields (OECD, 2017). The federal government has recently increased its employer data collection efforts (e.g., the 2016 National Household Education Surveys with questions about employer-provided training items; the new Annual Business Survey, beginning in 2017), as have many states, such as Colorado, Indiana, and Ohio (National Academies of Sciences, Engineering, and Medicine, 2017a). But these disparate efforts are not enough.

Stakeholders other than federal and state governments will need to work to create detailed workforce development data systems. Employers, education and training providers (public and private), and intermediary organizations (e.g., unions, manufacturing agencies) all need to work to construct and share quality data. For a subnational example, DTE Energy, an energy company in Michigan, regularly shares its data with community education partners to ensure that those partners understand DTE's workforce needs, including the number of electrical line workers that DTE will need and how they should be trained (National Academies of Sciences, Engineering and Medicine, 2017a). On a very local scale, then, DTE and its workforce development partners begin to approximate the more-robust, national workforce development systems of other OECD countries.

In the case of training providers like community colleges or nonprofits, those stakeholders must work to build transparent and detailed repositories of program characteristics, curricula, and instructional practices, based on transparent and detailed competencies and standards. Building a repository of postsecondary program features and curricula is feasible. A relevant example is that of credential repositories like Credential Engine that concatenate data on various credentials and their specific characteristics (e.g., expected time to completion). However, Credential Engine and other credential repositories typically do not have readily available, standardized national data on competencies and standards for key technical occupations in AM or other industries. And in fact, the analysis in the section on the landscape of education and training programs in AM with robotics was possible only because our RAND team constructed those data using program information made publicly available on the internet. An extension of the IPEDS, Credential Engine, or some other existing survey or data repository should include detailed and standardized information about program characteristics, curricula, and instructional practices. In the case of curricula and emphasized competencies, this will be an especially difficult task, because no standardized and sufficiently detailed competency model specifies the necessary skills that a program curriculum should emphasize, and because there is no standardized mechanism to collect program information based on this sort of competency model.[24] Standardized and sufficiently detailed competency models are necessary because placeholder competencies, such as "problem-solving," in existing competency and/or program models can mean a number of skills across a wide variety of industries and of occupations and jobs within those industries. Standardized data collection mechanisms, such as detailed surveys on actual instructional texts and practices, are necessary to assess how, if at all, a given program addresses these standardized competencies in practice.

Stakeholders other than federal and state governments will need to work to create detailed workforce development data systems.

Include a stronger emphasis on nontechnical, 21st-century skills in training and workforce development programs. Our analysis suggests that many AM sub-baccalaureate programs in institutions of higher education do not emphasize critical nontechnical work and personal effectiveness skills. It is exactly these skills that should grow in importance as robotics and other technologies used in AM become increasingly sophisticated, however. The apparent lack of attention paid to these nontechnical skills might be because most AM sub-baccalaureate programs are short enough to prohibit any significant emphasis on developing competencies in these skills. However, some programs, such as the AM programs at Wichita State University or programs available through the Michigan Coalition for Advanced Manufacturing, thread personal effectiveness and other nontechnical skills throughout their technical curricula or frontload those skills via bootcamps, providing students a chance to develop competencies in these skills along with the technical components of an AM technician job. Also, if robotics and other technologies used in AM innovate as rapidly as many expect, programs likely will have to spend less time teaching some technical skills as robots execute more and more routinized tasks. This is already happening in some settings. For example, Amazon now uses a number of robots in human-robot teams to reduce human time on certain tasks and thus the time it takes to train a human worker (Stevens, 2019). This "found time" given increasingly sophisticated industrial robots in AM can be spent on training in nontechnical skills in the classroom and at work. And, as before, program curricula and instruction related to these skills should be based on standardized and sufficiently detailed competencies that clearly specify and emphasize those 21st-century skills that are uniquely human and will arguably become even more critical under a future wave of roboticization and automation in AM.

Bring intermediary organizations to the education and training table more to bring employers to the table more. Postsecondary institutions are seen as the traditional provider of education and training for adults. But a number of recent federal and other initiatives (e.g., the Workforce Innovation and Opportunity Act of 2014; see Pub. L. 113-128, 2014) provide specific mechanisms to increase employers' direct participation in workforce development. Despite these initiatives, employers largely remain uncomfortable with addressing employee education and training themselves, and evidence suggests that employers might provide less on-the-job training than they have in the recent past (Giffi et al., 2018; Cappelli, 2015). Historically, unions and other intermediary organizations played a significant role in providing such training, but their member enrollments have declined over time (Holzer, 2015). With industries like AM—in which some 90 percent of employers are small to medium-sized firms with limited resources—intermediary organizations, such as the U.S. Chamber of Commerce, manufacturing institutes, and unions, still have a critical role to play in providing effective training services to AM employers. For example, Catalyst Connection is a member of the Manufacturing Extension Partnership (MEP) National Network in southwestern Pennsylvania; the MEP National Network is a network of public-private partnerships providing consulting, organizational development, and training services to small and medium-sized manufacturers.[25] The Training Within Industry program at Catalyst Connection provides instruction and a full curriculum to supervisors and managers responsible for the training and development of AM technicians. This train-the-trainer approach is common in many large firms; Catalyst Connection specifically provides training in and support for this approach for small to medium-sized AM firms. This approach appears to help fill a critical gap in employer supports, and it has the likely, synergistic benefit of helping bring all employers (including small and medium-sized employers) to the workforce development table in a deeper and more integrated way—if employers are trained and coached on how to provide training in critical technical and nontechnical skills directly to their employees. It remains the case that many small to medium-sized enterprise AM firms might not even be able to train the trainers, given human resource and other constraints. In that case, MEPs can provide trained coaches as a service to employees of small to medium-sized AM firms. These coaches can provide direct support to onboard or reskill workers at small to medium-sized enterprises in AM in both technical and nontechnical skills. Ideally, coaches as a service would complement other, ongoing employee training, including external training at area education and training providers, such as community colleges.

Conduct more-rigorous research on what works in education and training in AM for a wide variety of students, including new forms of education and training. Despite the recent renaissance in CTE in the United States, there remains a lack of rigorous research on career and technical training across the educational and labor market careers (e.g., see Jacob, 2017). The U.S. Departments of Education and Labor have begun to respond in kind with research funding focused on CTE. We might therefore have reliable answers to some questions about what works in CTE, when, and for whom in the near- to medium-term future.

The "for whom" is very important. Students in AM and other industries might hold full-time jobs while supporting dependents (Brock, 2010; Advisory

MEPs can provide trained coaches as a service to employees of small to medium-sized AM firms. These coaches can provide direct support to onboard or reskill workers at small to medium-sized enterprises in AM in both technical and nontechnical skills.

Committee on Student Financial Assistance, 2012). Additionally, some AM students might face significant difficulties in securing training and/or employment (e.g., returning to the workforce following incarceration). These students have not been the focus of much of the research on educational practices in career and technical training or otherwise. For example, although the research literature on the impacts of massive open and other online courses is relatively robust and growing, it mainly focuses on younger undergraduate and graduate students attending four-year institutions (see the previous section of the report, "Promising Practices in Education and Training for the Advanced Manufacturing Workforce").

At the same time, the existing research on CTE also mainly focuses on more-standard forms of (online) coursework. Yet newer instructional practices and technologies, such as threading nontechnical training into technical coursework or using social and cooperative online instruction to deliver some content, might be critical to shoring up weaknesses in training programs (e.g., the omission of field experiences in many sub-baccalaureate education and training programs; see Figure 11).

In conclusion, it is clear that many of the challenges that AM faces in education and training for technicians—detailed, quality data; comprehensive needs assessment analyses; and rigorous evaluation research on education and training interventions—are bound up in larger issues associated with workforce development in the United States. Renewed attention on workforce development more generally is therefore welcome in the expectation that it will help address some or all of these issues in AM.

However, stakeholders should consider the special needs of AM and AM using robotics in particular. One of those needs is the rather large share of AM firms that are small to medium-sized. These firms require special consideration if the U.S. manufacturing sector is to strengthen and grow. Policies and programs that support these firms are critical. Not incidentally, these supports and the partnerships that drive them (e.g., MEPs) are likely where innovative solutions to pressing workforce development problems in AM will come from, as small to medium-sized employers and intermediary organizations work together in meaningful ways to find solutions.

Finally, it can be easy to lose sight of the less educated and other workers that automation in AM will likely affect most, perhaps for the worse in the medium term. Being careful to understand, now, the job skills that less educated workers will need for the future and ensuring that education and training programs provide these skills are therefore critical to the success of AM.

Notes

[1] The term *21st-century skills*, which is formally associated with the nonprofit Partnership for 21st Century Skills (now Partnership for 21st Century Learning, or P21), refers to skills necessary to thrive in the contemporary economy, beyond traditional academic subjects. These skills formally include learning and thinking, literacy in information and communication technologies, and life skills. See Battelle for Kids, undated. The term is generally used to refer to the core skills associated with collaboration, communication, and critical thinking that are more unique to humans (e.g., see Boss, 2019).

[2] Not all experts agree that such a large skills gap exists in AM or other sectors of the economy; see, for example, Osterman and Weaver, 2014, and Sirkin, Zinser, and Rose, 2013. Some experts argue that estimates of anticipated skills gaps are often predicated on problematic employer survey self-reports; others argue that employers unnecessarily screen on educational credentials, are more stringent in job skill requirements during periods of relatively high unemployment, and/or might spend too few resources in recruiting an appropriate workforce despite marked declines in average employee tenure (Cappelli, 2015; Rothstein, 2012; Modestino, Shoag, and Ballance, 2016; Hollister, 2011; and OECD, 2017).

[3] The NAICS is a classification system used by U.S. and other North American countries' government agencies to distinguish different types of business establishments by primary economic activity. See U.S. Census Bureau, undated.

[4] For more information about the IFR, see IFR, undated.

[5] We selected the most recent academic year of IPEDS data, which was 2016–2017. We then selected two additional academic years, each about six academic years earlier than the previous academic year, to provide a sufficiently long period of observation before and after the Great Recession.

[6] See IPEDS, undated, for more information about the IPEDS.

[7] Postsecondary institutions are not the only providers of AM-related training for technicians. Employers, small and large, as well as a variety of for-profit and nonprofit agencies, provide relatively intense internal training programs (National Academies of Sciences, Engineering, and Medicine, 2017a; Burrowes et al., 2014). However, there currently are not many detailed data available for such programs, nationally or otherwise, and this has been the case for some time (e.g., see GAO, 2005; GAO, 2019).

[8] The CIP is used by the NCES to identify unique fields of study in postsecondary education. Please see the NCES website for more information on the CIP (NCES, undated).

[9] This strategy could result in the omission of some programs related to training in AM with robotics for technicians. However, the focus on fields specifically related to the CIP for "manufacturing" ensures that we assess relatively comparable programs directly related to AM. Furthermore, this analysis is intended to provide a first look at the supply of AM with robotics programs for technicians and the geographic distribution of those programs. Following our recommendations in the last section of this report, we recognize that a more detailed analysis of the supply of technician training programs in AM is critical for a robust needs assessment.

[10] The adjusted numbers of institutions shown in Figures 4, 5, and 6 are not reliable for sparsely populated areas. This is because sparsely populated areas are subject to greater statistical noise given small numbers of the event or phenomenon of interest in the geographic unit of interest (Gelman and Price, 2000). These maps are therefore meant only to provide a broad characterization of the geographic concentration of sub-baccalaureate manufacturing programs.

[11] Unlike the analysis in the preceding section, which focused on all programs in manufacturing at both community colleges and four-year universities and colleges in the United States, the present analysis focuses on sub-baccalaureate programs in AM with robotics offered in the Midwest and Pennsylvania at institutions, such as community colleges, that mainly focus on sub-baccalaureate programs.

[12] The ETA provides a repository of tools and data for job seekers via its CareerOneStop site, including information about available education and training programs. See CareerOneStop, 2020.

[13] See U.S. Department of Labor, Employment and Training Administration, 2010. For further details on this competency model, see also Manufacturing Institute, undated. According to this competency model, "personal effectiveness" skills include timeliness and showing initiative; "academic" skills include applied skills in reading, writing, math, and locating information, such as in an instruction manual; "workplace" skills include critical thinking, ability to work in teams, and general problem-solving; and "general technical" skills that are core to the occupation include safety, quality and measurement, maintenance installation and repair, production, and sustainable manufacturing. This competency model was developed by the ETA in collaboration with a wide variety of academic, industry, and other experts to isolate and emphasize the different competencies that AM workers would need to support a vital manufacturing sector (Ennis, 2008). Importantly, this model has been used previously by various AM stakeholders (e.g., the Manufacturing Institute) and includes knowledge, skills, and abilities highlighted in the ETA's O*NET system for occupations related to production technicians and related entry-level technical positions in AM. The O*NET serves as a central repository for occupational information and thus is intended as a resource for workforce development. Although there are many available competency models related to AM, we base our coding framework on the ETA's model given its direct links to O*NET and the generally broad base of stakeholder knowledge and expertise from which it draws.

[14] See U.S. Department of Labor, Employment and Training Administration, 2010, and endnote 13 of this report for more information.

[15] We define *academic skills* here as basic applied skills in reading, writing, and locating information (such as specific information in an instructional manual). We treat math skills as a separate category given the large share of sub-baccalaureate programs in AM with robotics that emphasize math in their curriculum. This is not the case with basic applied skills in non-math areas, such as reading, writing, and locating information.

[16] The O*NET serves as a central repository for occupational information and thus is intended as a resource for workforce development. See O*NET OnLine, 2020b. For the full O*NET

profile for a technician in AM with robotics, please see O*NET OnLine, 2020a.

[17] See WWC, 2020. Begun in 2002 by the U.S. Department of Education under the Education Sciences Reform Act, the WWC "reviews the existing research on different *programs*, *products*, *practices*, and *policies* in education. . . . to provide educators with the information they need to make evidence-based decisions," (What Works Clearinghouse, undated). The WWC reviews research related to the efficacy of education interventions based on rigorous and detailed standards adjudicating research quality and summarizes the quality of this evidence according to these standards. WWC standards are a widely accepted criterion in education research, including postsecondary and career and technical education. For more information, see WWC, undated.

[18] HarvardX and MITx are online programs through Harvard University and the Massachusetts Institute of Technology (MIT), respectively, via the nonprofit platform edX. For more information about edX, see edX, undated.

[19] See Carnegie Mellon Robotics Academy, undated, and University of Pittsburgh, undated. See also programs at DeVry University and The Foundery's now defunct program (DeVry University, undated; The Foundery, undated).

[20] Importantly, these experimental and quasi-experimental studies use some of the most-rigorous research designs highlighted in WWC standards.

[21] For more information on the CUNY ASAP, please see ASAP, undated.

[22] Very few needs assessments of the skilled technical labor market exist; the most rigorous of these tend to focus on supply and demand for workers based on the job vacancies and the duration of these vacancies by industries and occupations (e.g., Modestino, 2016). Overall, no readily available research provides a needs assessment of the AM labor market that considers technological diffusion, employer workforce demands, the supply of relevant education and training programs and their capacity and student outputs, and other relevant factors for understanding the local AM labor market and, thus, workforce needs.

[23] For example, the 2019 trade war between the United States and China might have negatively affected U.S. manufacturers (Strauss, 2019).

[24] As noted previously, the U.S. Department of Labor and others have published competency models, but these models are not sufficiently detailed.

[25] An MEP is a public-private partnership that receives federal funds to provide training and services for small to medium-sized firms; see National Academies of Sciences, Engineering, and Medicine, 2017b.

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Acknowledgments

We would like to thank Steve Catt, Rebecca Hartley, Annette Vickers, Lisa Masciantonio, Linda Wood, Gabriella Gonzalez, Kate Giglio, Krishna Kumar, John Pane, Susan Straus, and Shanthi Nataraj for their comments and assistance in writing this report. All errors are our own.

About This Report

This study was undertaken by RAND Education and Labor, a division of the RAND Corporation that conducts research on early childhood through post-secondary education programs, workforce development, and programs and policies affecting workers, entrepreneurship, and financial literacy and decisionmaking. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing official policies, either expressed or implied, of either ARM or the Office of the Secretary of Defense of the U.S. Government. The U.S. Government is authorized to reproduce and distribute reprints for Government purposes notwithstanding any copyright notation herein.

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The research described in this report was prepared for the Advanced Robotics for Manufacturing Institute (ARM) as part of its public-private partnership with the Office of the Secretary of Defense under Agreement Number W911NF-17-3-0004.

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RR-4244-ARMIP