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Training the Next Revolution in American Manufacturing

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A Report of the
CSIS SCHOLL CHAIR IN INTERNATIONAL BUSINESS

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Acknowledgments

This report is made possible by the generous support of HP Inc.

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1 | Introduction

Manufacturing remains a critical sector of the U.S. economy, accounting for millions of jobs and trillions of dollars in value to the economy. But the manufacturing sector as an employer peaked in mid-1979.[1] From that peak through 2010, the manufacturing sector shed over eight million jobs. By 2010, the manufacturing labor force reached an inflection point and since then manufacturing jobs have made a slow but steady recovery, now employing nearly 13 million individuals in the United States, according to the latest figures from the U.S. Bureau of Labor Statistics.[2] Nevertheless, the country remains a long way from its manufacturing peaks. In 1953, 32 percent of all U.S. workers held manufacturing jobs. In absolute numbers, 1979 represents the peak at 19.5 million jobs—26.4 percent of the workforce. By the end of 2018, despite eight years of solid growth, the 12.8 million individuals employed in the manufacturing sector[3] represented just about 8 percent of the labor force.[4]

Yet employment represents only part of the picture. As YiLi Chien and Paul Morris at the Federal Reserve Bank of St. Louis write, "Manufacturing's share of real GDP has been fairly constant since the 1940s, ranging from 11.3 percent to 13.6 percent. It sat at 11.7 percent in 2015."[5] In other words, while fewer Americans are working in the manufacturing sector, U.S. manufacturers have kept up with the rest of the economy over the past eight decades.

Many factors have contributed to this dichotomy. First, the U.S. workforce has steadily aged. The Bureau of Labor Statistics estimates that the ratio of Americans aged 65 and over in the workforce has risen from 12 percent in the 1990s to over 18 percent today.[6] As a December 2017 Senate Report on Aging explains, "After the age of 65…the composition of the labor force changes. The proportion of older workers in the manufacturing sector

1. "All Employees: Manufacturing," FRED, https://fred.stlouisfed.org/series/MANEMP.
2. Ibid.
3. Ibid.
4. "Bureau of Labor Statistics Data." U.S. Bureau of Labor Statistics. https://data.bls.gov/timeseries/LNS12000000. Percent calculated by dividing total manufacturing workforce in December 2018 by total U.S. labor force in December 2018.
5. "Is U.S. Manufacturing Really Declining?" Federal Reserve Bank of St. Louis, April 10, 2017, https://www.stlouisfed.org/on-the-economy/2017/april/us-manufacturing-really-declining.
6. Erika McEntarfer, "What Is Ahead for the Nation's Aging Workforce?" U.S. Census Bureau, April 24, 2018, https://www.census.gov/library/stories/2018/04/aging-workforce.html.

decreases."[7] While 10.5 percent of 25 to 54-year-old U.S. workers are employed by the manufacturing sector, only 7.3 percent of senior citizen workers are.[8]

Second, productivity rates for U.S. manufacturing have risen. Despite the decline in manufacturing employment noted above, output has increased. In 2016, while Presidential candidates complained that manufacturing jobs had disappeared, the country's manufacturers were producing 47 percent more than they had two decades earlier, according to Harvard economist Greg Mankiw. Mankiw explained, "Producing more output with fewer workers is called higher productivity, which in turn is driven by technological innovation."[9]

Darrell West of the Brookings Institution agreed that advances in technology had reshaped the manufacturing sector. West wrote, "Robots are helping to increase overall output and save money, but not helping to add jobs." While manufacturing output rose 10 to 20 percent from 2010 to 2016, West found the corresponding increase in manufacturing jobs was only 2 to 5 percent.[10]

Still, manufacturing jobs are not being filled despite the low pace of new employment opportunities. This is due to a growing skills gap between what workers are trained to do and what a twenty-first century manufacturing job requires. A study by Deloitte and the Manufacturing Institute found that 2.4 million manufacturing positions could be left vacant between 2018 and 2028 due to workers lacking the skills necessary to fill those jobs. Currently, 80 percent of manufacturers claim a moderate or serious shortage of qualified applicants to fill skilled manufacturing positions. Deloitte projects that $454 billion in manufacturing GDP could be put at risk if those projected job openings cannot be filled. Manufacturers surveyed by Deloitte and the Manufacturing Institute reported that the skills shortage may worsen over the next three years. Further, most manufacturers surveyed for the study reported that the top cause of skills shortages is the "shifting skill set due to the introduction of new advanced technology and automation."[11]

Future of Work Due to Changing Technology

Changes in technology almost always lead to churn in the workforce: before robots and machines, the assembly line and steam engine boosted growth, but at the cost of jobs. As the McKinsey Global Institute notes, however, "the speed with which automation technologies are developing today, and the scale at which they could disrupt the world of work, are largely without precedent."[12]

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7. U.S. Congress, Senate, Special Committee on Aging, *America's Aging Workforce: Opportunities and Challenges*, 115th Cong., 1st sess., 2017, S. Rept., https://www.aging.senate.gov/imo/media/doc/Aging Workforce Report FINAL.pdf.
8. Ibid.
9. N. Gregory Mankiw, "The Economy Is Rigged, and Other Presidential Campaign Myths," *The New York Times*, May 06, 2016, https://www.nytimes.com/2016/05/08/upshot/the-economy-is-rigged-and-other-presidential-campaign-myths.html.
10. Darrell M. West, "How technology is changing manufacturing," Brookings, July 29, 2016. https://www.brookings.edu/blog/techtank/2016/06/02/how-technology-is-changing-manufacturing/.
11. Craig A. Giffi et al., *The jobs are here, but where are the people?* (Deloitte and The Manufacturing Institute, 2018).
12. James Manyika, "Technology, jobs, and the future of work," McKinsey & Company, May 2017, https://www.mckinsey.com/featured-insights/employment-and-growth/technology-jobs-and-the-future-of-work.

Robotics, artificial intelligence, and other technological advances will not affect all workers equally. According to McKinsey, highly skilled workers will benefit from technological advances while lower-skilled workers might not. Lower-skilled workers will be able to achieve advances in productivity, but this, in turn, will increase the available supply of similar low-skilled workers in their industries and provide downward pressure on wages.[13]

Worse than a decrease in wages, some workers could see their professions eliminated by technologies. The most oft-cited example has to do with autonomous driving technologies and the five million Americans who make their livings driving taxis, buses, vans, trucks, and other vehicles—3 percent of the entire U.S. workforce.[14] But manufacturers provide another good hypothetical example, both at home and abroad. A 2016 study by the International Labor Organization found that 88 percent of textile workers in Cambodia were "at high risk of automation" from technological changes.[15] Closer to home, Walmart now sells bathmats and towels that are entirely machine-sewn—no humans involved at all—with labels that read "Made in the USA."[16]

Lost manufacturing jobs represent a challenge for both advanced and developing economies. For developing countries, manufacturing represents what Harvard economist Dani Rodrik calls *an escalator*—"a great absorber of unskilled labor" that allows countries to move agricultural workers into higher value-added industries.[17] For industrialized countries, the loss of manufacturing jobs due to automation disproportionately hurts those at the bottom of the skill spectrum, further widening the gap between the haves and the have nots. This can produce unequal societies and foster resentment between groups of people, with resulting political consequences.[18]

Of course, automation and technological advancements also create new jobs. According to a study by the World Economic Forum, automation and new technologies will have displaced 75 million jobs by 2022 but create 133 million new jobs, particularly in services.[19] As robots replace some jobs, workers are freed up to take on new jobs, some of which do not yet exist. One-third of new U.S. jobs created in the past quarter-century didn't exist before that time.[20] There will also be a shift within manufacturing industries. According to Molly Kinder, Senior Adviser at New America, even within specific factories, "the jobs that have disappeared are disproportionately those at the bottom of the skill spectrum."[21] In the future, new technology will require all workers—including manufacturers—to build new skills.

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13. Ibid.
14. Steven Greenhouse, "Autonomous vehicles could cost America 5 million jobs. What should we do about it?" *Los Angeles Times*, September 22, 2016, http://www.latimes.com/opinion/op-ed/la-oe-greenhouse-driverless-job-loss-20160922-snap-story.html.
15. Christina Larson, "Closing the Factory Doors," *Foreign Policy*, July 16, 2018, https://foreignpolicy.com/2018/07/16/closing-the-factory-doors-manufacturing-economy-automation-jobs-developing/.
16. Ibid.
17. Dani Rodrik, *Work and Human Development In a Deindustrializing World* (New York, NY: United Nations Development Programme, 2015), http://hdr.undp.org/sites/default/files/rodrik_hdr_2015_final.pdf.
18. John Russo and Sherry Lee Linkon, "The Social Costs of Deindustrialization," in *Manufacturing a Better Future for America*, edited by Richard McCormack (Washington, D.C.: Alliance for American Manufacturing, 2008): 183-216.
19. Centre for the New Economy and Society, *The Future of Jobs Report 2018* (Geneva, Switzerland: World Economic Forum, 2018), p.viii, http://www3.weforum.org/docs/WEF_Future_of_Jobs_2018.pdf,.
20. James Manyika, "Technology, jobs, and the future of work."
21. Molly Kinder, "Learning to Work With Robots," *Foreign Policy*, July 13, 2018, https://foreignpolicy.com/2018/07/11/learning-to-work-with-robots-automation-ai-labor/.

Changing Needs of Employers

While the overall makeup of the workforce has shifted away from manufacturing and toward services jobs, the makeup of jobs within the manufacturing sector has evolved as well. In fact, these changes mirror one another: from lower-skilled, lower-paying jobs to higher-skilled and higher-paying ones.

The National Association of Manufacturers (NAM) describes the shift within the manufacturing sector as a move from "low-paying, low-skilled jobs in facilities that are dark, dirty and dangerous" to "well-paying, skilled jobs with upward mobility."[22] Many U.S. workers who worked in yesterday's manufacturing industries might not have the skills for more advanced manufacturing jobs.

This has resulted in a mismatch between the manufacturing skills needed previously and the skills needed now in the twenty-first century economy. Manufacturing jobs are, as stated earlier, on the rise. But manufacturing jobs require more and different skills than before. Employers are having trouble finding the right workers. Currently, 390,000 manufacturing jobs remain unfilled, with most left empty because they require workers trained in high-skilled manufacturing methods. As Justin Guinn, a Content Analyst at Software Advice, explains, "The prevalence of computer-controlled machinery…now demands manufacturing workers that possess a combination of math skills, intuition, stamina, and often a college degree."[23]

In the future, Guinn says, a can-do attitude won't be enough to land and perform a manufacturing job. "We've moved out of an age where a pair of hands, a strong back, and a healthy work ethic is all that's needed to get a good paying job in manufacturing."[24] The jobs have returned, but workers will need to have the skills and training to understand new machines and use critical thinking to perform more complex tasks.

Educational Landscape in the United States

Educational institutions in the United States are at the front line meeting the skills needs of the modern workforce. However, in-demand advanced manufacturing skills are changing at a rapid pace. This challenges educational institutions to quickly adapt to the most current skills, which may be vastly different, in order to meet the needs of particular employers in their areas. It can also be challenging for employees and employers, who may need additional mid-career education (compared to previous generations) to upskill the incumbent workforce.

In recent years, public secondary schools have increasingly focused on education in Science, Technology, Engineering, and Mathematics (STEM). While these skills are necessary in the modern workforce, there has been less emphasis on how STEM skills can be applied to vocational or technical training. There is a perception that college

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22. National Association of Manufacturers, *Overcoming the Manufacturing Skills Gap: A Guide For Building a Workforce-Ready Talent Pipeline in Your Community* (Washington, D.C.: National Association of Manufacturers, 2014), http://www.nam.org/Issues/Workforce-and-Immigration/Workforce-Task-Force-Toolkit/Overcoming-the-Manufacturing-Skills-Gap-2147476066/.
23. Justin Guinn, "Manufacturers Are Hiring Again; What Skills Are They Looking For?" Software Advice, September 19, 2017, https://www.softwareadvice.com/resources/manufacturers-skills-in-demand/.
24. Ibid.

or college-prep is the preferred route for students, while skills-based training for jobs available immediately after high school is less-preferred. Many schools have eliminated or significantly reduced programs that taught a curriculum focused on vocational skills, with the number of career and technical education credits earned by U.S. high school students dropping 14 percent between 1990 and 2009.[25]

Post-secondary community colleges and technical schools have long played a role in upskilling workers to meet the needs of local employers. However, there is wide variation in the approaches these institutions take. In some states, community colleges are run as a statewide system, allowing more coordination across campuses and giving potential students access to statewide resources even at their local institution. In other states, there is less coordination but greater flexibility and freedom for local institutions to partner directly with local employers to create unique programs to meet employers' needs.

Government Response to Workforce Needs

The federal government has played a role in the skills of the workforce since the "Manpower Administration"—now known as the Employment and Training Administration (ETA)—was founded in 1954. ETA, which is located within the U.S. Department of Labor, administers a number of different programs and both directly and indirectly funds programs operated by states, local governments, and public-private partnerships. However, other federal departments and agencies have a large influence on the skilled workforce, including the Department of Education, which sets standards for secondary schools, vocational education, and colleges, and the Departments of Defense and Veterans Affairs, which both set standards for the skills of active duty servicemembers as well as help with their transition to civilian jobs after their service ends.

The federal government is aware of the opportunities and challenges facing U.S. manufacturing today. President Trump signed executive orders in the summer of 2018 that encourage worker training and apprenticeship programs and established the National Council for the American Worker and the American Workforce Policy Advisory Board. The emphasis on expanding access to apprenticeship programs is noteworthy.

The Department of Labor has led the White House's approach to increasing the skills needed for the next era of manufacturing. The Department has encouraged companies, trade associations, and labor unions to develop their own "industry-recognized apprenticeship guidelines."[26] Promoting apprenticeships, especially in new sectors, is the crux of the White House's plan. As the Trump Administration notes, "[Department of Labor] data shows that over 90 percent of apprentices find employment after completing their program, and their average starting wage is $60,000 annually.

Secretary of Labor Alexander Acosta has chaired the effort thus far. This past summer, his department released $84.4 million in grants to community groups, states, and

25. Brian A. Jacob, *What we know about Career and Technical Education in high school* (Washington, D.C.: Brookings, 2017), https://www.brookings.edu/research/what-we-know-about-career-and-technical-education-in-high-school/.
26. "President Trump Leads on Workforce Development," The White House, June 15, 2017, https://www.whitehouse.gov/briefings-statements/president-trump-leads-workforce-development/.

municipalities, with an eye to filling open jobs where skills are hard to find.[27] But while the shift to focusing on skills training and apprenticeships is noteworthy, these are still early stages, and more can be done.

Federal efforts to increase workforce development and education opportunities are extensive and well publicized. Below is a list of recent workforce development programs from the Department of Labor and their funding levels:

Table 1: Recent Government Programs

Trade Adjustment Assistance Community College and Career Training (TAACCCT) Program[28]	This program is a $1.9 billion grant designed to increase the capacity of community colleges and 2-year programs at 4-year colleges to train workers in industry-accepted credentials and skills. Intended to help workers eligible under the Trade Adjustment Assistance Program, it also supports other unemployed workers. The program issued 256 grants through September 2018 and supported 478,434 students in TAACCCT programs across 2,678 programs of study.[29]
Job-Driven National Emergency Grant Program	This program awarded $154.8 million in 2014 to 32 states, Puerto Rico, and the Cherokee Tribe to train workers, who lost jobs through no fault of their own, in high-demand industry jobs.[30]
American Apprenticeship Grants	This program awarded $175 million in 2016 to 46 public-private partnerships to expand high-quality apprenticeships. The winning grantees pledged to hire 34,000 more new apprentices in high-tech and high-growth industries over five years.[31]
State Expansion Grants under the Apprenticeship USA Initiative	This program awarded $50.5 million in 2016 to 37 grantees across the country. The grants are intended to improve cooperation between stakeholders to develop innovative systems to increase apprenticeships as a training strategy.[32] The Department of Labor continues to fund this at $50 million in 2018 and set a goal of 10 percent growth over the next two years.[33]
YouthBuild Programs	In existence since 2006, the Department of Labor will fund $85 million in grants in 2018 to support and expand the program, which aims to educate at-risk youths in applicable construction skills and provide them with a high school diploma or GED.[34]
Key Industry Sectors Grants	The Department announced in 2018 $150 million in grants to expand apprenticeships on a national scale in key industry sectors. This effort will promote a sector-based approach to a large-scale expansion of apprenticeships. The apprenticeships should result in the issuance of an industry-recognized credential and meet quality standards.[35]

27. Alexander Acosta, "Reinvesting in the American Workforce," *The Post and Courier*, July 20, 2018, https://www.postandcourier.com/opinion/commentary/reinvesting-in-the-american-workforce/article_5ce-ab664-8c3b-11e8-b5e5-b33e5e9b56ec.html.
28. "Trade Adjustment Assistance Community College and Career Training," U.S. Department of Labor Employment and Training Administration, https://www.doleta.gov/taaccct/.
29. "Trade Adjustment Assistance Community College and Career Training (TAACCCT) Program Fact Sheet," U.S. Department of Labor Employment and Training Administration, https://www.doleta.gov/taaccct/pdf/TAAC-CCT-Fact-Sheet-Program-Information.pdf.
30. "$154.8M awarded to 32 states, Puerto Rico and the Cherokee tribal nation to implement or expand job-driven training programs for laid-off workers," U.S. Department of Labor, June 26, 2014, https://www.dol.gov/newsroom/releases/eta/eta20141235.
31. "Apprenticeship Grant Opportunities," U.S. Department of Labor, https://www.dol.gov/featured/apprenticeship/grants.
32. "DOL Announces $50.5 Million in Apprenticeship State Expansion Grants," National Skills Coalition, October 21, 2016, https://www.nationalskillscoalition.org/news/blog/dol-announces-50-5-million-in-apprenticeship-state-expansion-grants.
33. Apprenticeship Grant Opportunities," U.S. Department of Labor.
34. "U.S. Department of Labor Announces YouthBuild Funding Opportunity," U.S. Department of Labor, May 18, 2018, https://www.dol.gov/newsroom/releases/eta/eta20180518.
35. "U.S. Department of Labor Announces Funding Opportunity For Apprenticeship Expansion in Key Industry Sectors | U.S. Department of Labor," U.S. Department of Labor, July 18, 2018, https://www.dol.gov/newsroom/

Many of the programs we studied take advantage of the federal programs and funding outlined above to help fund their own respective project and training programs. Federal funding remains a key part of the current ecosystem of workforce development and training.

The Study

The purpose of this study is to gain a better understanding of the ongoing efforts on advanced manufacturing training below the federal—or even state-wide—level. According to the Organization for Economic Cooperation and Development (OECD), advanced manufacturing technology can be defined as "computer-controlled or micro-electronics-based equipment used in the design, manufacture, or handling of a product."[36] This includes a wide range of processes and devices, usually characterized by the use of complex technology and innovative methods to produce new, cutting-edge goods. 3-D printing, automation and robotics, and nanotechnologies can all fit under the umbrella of advanced manufacturing.[37] This study was specifically focused on initiatives in the private sector and at academic institutions, with the goal of surveying what nongovernment efforts are underway to educate the workforce on advanced manufacturing techniques. We approached this task with several initial questions: What are these programs doing? How effective are they? What lessons and best practices can be applied more widely to encourage success?

To do this, we studied a number of players in this space, from community colleges and four-year institutions to national certification organizations. We also sought a sample size across a wide geographic range of the United States, particularly in the Midwest and the Southeast. We conducted site visits, in-person interviews, and phone interviews of these organizations to gain a better understanding of current activities and efforts in the field. Additionally, we sent out a survey to relevant groups to expand our sample size and geographic scope.

The following sections summarize our individual interviews with these stakeholders, highlight our findings from the survey and interviews, and provide several recommendations for effective ways to promote advanced manufacturing capabilities.

releases/eta/eta20180718.

36. "Advanced Manufacturing Technology," OECD Glossary of Statistical Terms, https://stats.oecd.org/glossary/detail.asp?ID=52.

37. "About Advanced Manufacturing," Australian Department of Industry, Innovation and Science, https://archive.industry.gov.au/industry/IndustrySectors/Advanced-Manufacturing/Pages/default.aspx.

Table 2: Summaries of Analyzed Programs

Program	***Location***	***Type***	***Degree or certificate granting program?***	***Non-educational resource support?***	***Maker space present?***	***High school outreach or boot camp programming?***
Robert C. Byrd Institute	WV	Community workforce development resource support	No (supports degree-granting institutions)	No	Yes	No (though the institutions it supports do)
Center for Manufacturing Innovation	SC	Manufacturing specific-training facility	Yes (affiliated with Greenville Tech)	No (student services through affiliated school)	Yes	Yes
Siemens Gas Turbine Factory	NC	Private corporation apprentice-ship	Yes (covers tuition at local comm. college)	No	No	Yes (pre-apprenticeship as part of application process)
University of Pittsburgh Manufacturing Assistance Program	PA	Manufacturing specific-training facility, community workforce development resource support, traditional four-year university	Yes	Yes: transportation assistance, drug testing	Yes	No
Cuyahoga Community College	OH	Community college	Yes	No	Yes	No
Ivy Tech Community College	IN	Community college	Yes	No	No	No
Ohio Manufacturing Partnership	OH	Government-funded resource support	No (supports degree-granting institutions)	Yes: transportation assistance	No	Yes
FREEDM Systems Center and PowerAmerica	NC	Traditional four-year university	Yes (credit toward undergraduate degree at affiliate university)	No	No (some equipment for demos)	Yes (for undergraduate students)
Wayne County Schools Career Center	OH	Government-funded resource support	No	Yes: drug testing, drug treatment and counseling	No	Yes (high school career counseling)
Indiana University Manufacturing Policy Initiative	IN	Traditional four-year university, policy analysis and research	Yes	No	No	No

America Makes	Nationwide digital presence, physical locations in TX and OH	Digital resource support	No	No	No	Yes (in Youngstown, OH location)
ToolingU-SME	Nationwide digital presence	Digital resource support	No	No	No	No

INTERVIEW DETAILS

Robert C. Byrd Institute

Charleston, WV (located on Marshall University's South Charleston Campus)
Bridgeport, WV (part of Advanced Manufacturing Technology Center)
http://www.rcbi.org/

Met with:

Lucinda Curry, Director of Apprenticeship Works
Jackie Frail and Becky Calwell, Program Managers
Jerry Jefferson and Doug Currence, Technical Trainers

The Robert C. Byrd Institute (RCBI) is an organization in West Virginia that offers a range of resources both to employers and employees in manufacturing industries. It was started over 30 years ago primarily with Department of Defense funding (through DARPA) to assist manufacturers in building capacity.

RCBI now offers programs at three sites in West Virginia, with each site offering a particular focus. The Huntington location, on the campus of Mountwest Community College, primarily focuses on biomedical and education markets. The Charleston location, located on Marshall University's South Charleston campus, primarily serves the metals, transportation, and energy markets. The Bridgeport location, part of an aviation campus in collaboration with NASA, primarily serves aerospace, transportation, composites, government, and oil and gas markets. All three sites have basic manufacturing education, and all three can offer training in advanced manufacturing techniques, including 3-D printing. All three sites also offer summer boot camps for middle and high school age students.

RCBI is not a degree-granting institution itself; however, it does partner with community colleges and technical schools. The associated school manages the students (including tuition and arranging financial aid), determines which courses will be offered, and what credits or certifications the courses qualify for. RCBI provides instructors, lab space and equipment rental, and some assistance with planning curriculum.

RCBI offers several types of assistance directly to employers. Employers can sign up their employees for training courses which can be taken at an RCBI location or hire an RCBI instructor to provide on-site instruction at the employer's worksite. RCBI provides assistance to employers who want to set up an apprenticeship program. It strongly encourages employers to use registered apprenticeship programs (because they can access

several grants and subsidies), but it will help employers even if they don't want to go through the registration process.

RCBI is a partner organization with ApprenticeshipWorks, which helps set standards and certifications for registered apprenticeships. Under a grant from the U.S. Department of Labor, it recently helped write nationwide standards for apprenticeships in additive manufacturing/3-D printing technicians.

RCBI is very focused on apprenticeships, and many of its boot camp-type programs have been reoriented towards a "pre-apprenticeship" model. It will help set up pre-apprenticeship programs for high school students, and it also has programs for veterans and women. For example, a women's pre-apprenticeship is operated and funded through West Virginia Women Work (wvwomenwork.org). Programs like this have a high success rate of getting these communities into advanced manufacturing apprenticeships.

RCBI also operates maker spaces (theirs is called "Maker Vault"), so its labs, computers, and smaller equipment are available to local entrepreneurs and small businesses for a small monthly fee. Time on larger equipment as well as staff to help operate it are also available for purchase. RCBI maintains regular interaction and collaboration with many of the businesses in their area, both through formal associations and paid training as well as informal interactions.

It was apparent that all of the staff were committed to helping and encouraging local businesses. One of the training instructors showed off a few items he had helped local businesses with. In one case, he had helped modify the mold for a company that produces plastic Christmas tree stands: using a 3-D design and additive process, he was able to develop a mold that could be more efficiently water-cooled, reducing the time for the plastic to cool and increasing the productivity of the factory. In another case, a 3-D model of a skull and sinus cavity had been developed using CAT scans of a patient, so the doctor at West Virginia University School of Medicine could do a trial run of a difficult operation on the model before attempting it on the patient.

Center for Manufacturing Innovation

Greenville, SC
www.cmigreenville.com

Met with:

David Clayton, CMI Director

The Center for Manufacturing Innovation (CMI) provides an advanced manufacturing training center on the campus of Greenville Technical College. The new $25 million facility opened in 2016 and features classrooms and lab and shop space. Most of the equipment, including a few plastics and metal 3-D printers, was donated by GE and Haas, which have operations in the area. They provide a mix of programs, including summer camps for high school, pre-apprenticeship boot camps, apprenticeship continuing education requested by employers, and more. Coursework can be tailored directly to an employer's need (if they have enough students to fill a class). Regular classes are offered through Greenville

Tech, and a cooperative arrangement with Clemson University allows researcher access to the facilities as well as some course credit for engineering students. The collaborative arrangement between educators, engineers, and employers was highlighted as a key factor in its success (and it helps to have the entire campus nearby, including the Clemson University International Center for Automotive Research). CMI also has a maker space and offers small businesses and self-employed entrepreneurs access to the shop for prototyping.

They feel the biggest challenge is often getting students in the door. They believe they have a lot of success getting students to complete programs they start—often because they are part of either apprenticeships with an employer or are part of an associate's degree program. They also have a very high job placement rate (but didn't have exact figures, since they have students across a number of different programs). There is a perception that high schools and parents are focused on encouraging their children to go to college, and they overlook jobs in manufacturing. They sometimes struggle to fill some classes enough to justify an instructor.

Siemens Gas Turbine Factory

Charlotte, NC

Met with:

Dawn Braswell, Training Manager

Siemens purchased the power generation division of Westinghouse in 1998 and has been expanding the existing gas turbine facility in Charlotte, North Carolina in recent years. As a German company operating in the United States, it has a very specific model of apprenticeship developed and modified to fit into the U.S. landscape.

The model is a four-year program for apprenticeship. Siemens prefers to bring on a cohort of apprentices who stay together throughout the program; currently, there are approximately two dozen apprentices total, usually with four to eight in each cohort. The program includes coursework through a local community college resulting in an associate's degree as well as direct training in each of the divisions of factory operations. The apprentice also receives a journeyman certificate. An apprentice is paired with a mentor at the company, who also receives training-of-trainers. Also, third and fourth year apprentices are often paired with new, first year apprentices.

The biggest challenge they identify is finding qualified applicants. To that end, Siemens has expanded marketing efforts at local high schools and also partnered with a few other employers and the local community college to offer a pre-apprenticeship boot camp. During the boot camp, students are able to visit several local employers as well as begin some basic coursework. At the end of the boot camp, employers and students engage in a matching process so they can each select where they feel the best fit can be achieved.

The cost of the program to Siemens is $180,000 per person for four years, including the apprentice's salary and tuition and fees.

University of Pittsburgh Manufacturing Assistance Center (UPitt MAC)

Pittsburgh, PA
https://www.engineering.pitt.edu/mac/

Met with:

Claire Guth, Director of Outreach
Dr. David I. Cleland, Co-Director

The University of Pittsburgh Manufacturing Assistance Center (MAC) was founded in 1994 but relocated in 2017 to a new facility in Homewood, an economically depressed area of Pittsburgh. Its new facility includes standard shop equipment for basic manufacturing techniques (lathes, mills, surface grinders, and drill presses) as well as equipment for advanced manufacturing techniques (including HAAS and MAZAK CNC machines, 3-D plastics printers, and a computer lab with CAD/CAM software). The facility is in a former Westinghouse Electric plant, and it now contains space for 20 different local companies and organizations.

Since moving, the Center has had approximately 70 students across various programs. It offers basic boot camp courses in machining, CNC, and CAD. Courses can count towards up to 18 credit hours at the University of Pittsburgh, but so far only two students in the engineering program have taken coursework at MAC. Students who complete their basic courses have a very high job placement rate, upwards of 95 percent.

The biggest challenge MAC faces is getting students into courses. Since moving to the Homewood area, it has received a lot of interest from people in the neighborhood. While they don't keep metrics on this, they estimate approximately 40 percent of people who walk in the door off the street go on to take a class (and indeed I observed someone coming in during the visit). Nevertheless, it is still difficult to fill a whole class to make it economically sustainable.

Students themselves face a number of challenges characteristic of underserved communities. Many are limited by transportation, either because they do not have a car or have had their driver's license revoked. Through partner organizations like The Trade Institute of Pittsburgh (located in the same facility), they reach out to recently released convicts who need training and a good job. Students who are successful in lower-level trade programs are often recommended for manufacturing training programs. Through the University of Pittsburgh as well as local government, they try to provide more "wrap-around" services like helping students access transportation benefits as well as occasionally offering drug testing that can be used for screening by potential employers.

MAC has also been reaching out to local employers; it currently has relationships with about a dozen companies to help provide instruction as part of its apprenticeship programs. It is working to encourage more companies to develop apprenticeships, both for new workers as well as for upskilling incumbent workers. MAC encourages employers to use registered apprenticeships so they can access subsidies available through government programs. They have been able to double the stipend amount available through the Allegheny County Workforce Development Board.

Cuyahoga Community College

Cleveland, OH
https://www.tri-c.edu/

Spoke with:

Alethea Ganaway, Additive Manufacturing Program Manager

Cuyahoga Community College remains Ohio's oldest and largest public community college, with thirteen campuses across northeast Ohio. Cuyahoga, in collaboration with America Makes, began offering programs in additive manufacturing and 3-D printing and opened a new Ideation Station in 2015. Since then it has averaged about 18 students per year who start a program in the fall and granted about 35 short term certificates and 14 one-year certificates in additive manufacturing. Of those students who completed the entire program, 80 percent were placed in jobs, and 14 percent stayed at their current employer.

The Ideation Station operates as a maker space, and is available to community groups, schools, and entrepreneurs and small businesses. They are also finding ways to use this space to collaborate with students in other programs, even many that aren't directly related to manufacturing. For example, a theater or arts program could use the 3-D printers to help develop sets. It opens up new areas of creativity for students and shows how innovative tools can impact many different fields.

Ivy Tech Community College

Indiana, statewide
https://www.ivytech.edu/

Spoke with:

Chancellor Thomas G. Coley, South Bend and Elkhart locations

Ivy Tech operates the public community colleges of Indiana, with more than 40 locations, and teaches classes in more than 75 communities across the state. It is the largest single-accredited statewide community college system in the entire country.

We spoke with Thomas G. Coley, regional chancellor of South Bend and Elkhart. Elkhart at one point had the highest unemployment in the country, particularly after a number of RV manufacturers closed. However, now unemployment is under 3 percent, so employers are having difficulty filling available job openings. And often even when an opening is available, there aren't enough potential workers with the right skills.

Chancellor Coley noted, "the hottest thing for us is apprenticeships," as a way to integrate education into meeting the workforce needs of employers. He recently made a trip to Germany and Switzerland to evaluate their models and see how they could be implemented in Indiana. He notes that moving to an apprenticeship model allows a more hands-on approach. Instead of a 16-week program with classwork or lab work every day, the model is fewer days in class over a longer period of time, hopefully three to four years, with employers providing on-the-job training that is supplemented by classroom

instruction. Apprenticeship programs can provide credits toward an associate's or bachelor's degree upon completion.

In Indiana, most of the apprenticeship programs are run directly by labor unions and not by the employers. There are about 100 apprentices in union-run programs in Elkhart and South Bend. They also have about a dozen employers with apprenticeship programs on their own, with about 16 active apprentices, and are exploring ways to use grants from the Department of Labor for additional apprenticeships.

Ohio Manufacturing Extension Partnership (Ohio MEP)

Cleveland, OH
https://development.ohio.gov/bs/bs_mep.htm

Spoke with:

Susan Foltz, Office of Small Business and Entrepreneurship

The U.S. Department of Commerce's National Institute of Standards and Technology (NIST) funds Manufacturing Extension Partnership (MEP) programs in every state. These programs combine funding from the federal government with local public-private partnerships to support local manufacturing companies and workforce development. The Department of Commerce provides states broad leeway in how they implement MEP funding.

In Ohio, the statewide MEP partners with six local organizations, each a mix of public and private stakeholders as well as a mix of Ohio's universities and community colleges. Ohio MEP is responsible for setting direction, convening roundtables with industry leaders, and providing oversight and evaluation.

Ohio is currently very invested in the apprenticeship model and is working to improve the pipeline. MEP notes that this starts with reaching out to students, even in middle schools, to show them that careers in manufacturing are good. Susan noted, "Manufacturing has changed: it's not that 'dirty' environment." Much of her work is helping reshape the perceptions of both students and parents.

A well-implemented apprenticeship is generally partnered with a community college, so it should result in an associate's degree upon completion. There is funding (up to $2,500 per apprentice) for registered apprenticeships, which include these education requirements to ensure employees receive credit towards a degree or certification.

Ohio MEP has also been focused on pre-apprenticeship programs, with up to $1,500 available for students (usually through a community college). Ohio MEP has funded approximately 70 pre-apprenticeship students in the past, but it is expanding and has a goal of 100 additional students in programs this school year. In the past, these programs have had a 70-80 percent placement rate into full apprenticeship programs. Both Lorraine County Community College and Cuyahoga Community College have been leaders in developing strong career pathways through pre-apprenticeship programs.

One of the biggest challenges students and potential workers face, particularly in the Cleveland area, is transportation. Many students come from lower-income households that

are more dependent on public transit, so Ohio MEP has been devoting some resources to helping students meet their public transit costs. For example, a group of eight manufacturers at an industrial park in Avon, Ohio, approximately 20 miles outside of Cleveland, have partnered together to help apprentices and employees access the jobs in their area.

FREEDM Systems Center and PowerAmerica

On the campus of North Carolina State University (NC State)
Raleigh, NC
https://www.freedm.ncsu.edu/
https://poweramericainstitute.org/

Spoke with:

Pam Carpenter, Education Director

PowerAmerica is a partner organization of ManufacturingUSA, and through public-private partnerships, they provide grant funding to promote early-stage research. They also devote resources to workforce development programs.

At NC State, they operate the FREEDM Systems Center (www.freedm.ncsu.edu), which is one of the latest Gen-III Engineering Research Centers (ERC) established by the National Science Foundation in 2008 to develop technology to integrate the nation's power grid with renewable electrical energy technologies. This center allows students to gain a broad range of technical expertise using advanced manufacturing techniques.

FREEDM began primarily as an engineering research model, but it has added technical and professional skills programs. Still, however, the focus is primarily on undergraduate students at NC State. It does have a 10-week skills summer boot camp that is also primarily targeted at undergraduate engineering students.

FREEDM has relationships with local community colleges to share best practices for the current skills needs for advanced manufacturing employers, and it has a few “training for teachers” courses to help educators. It has tried to develop programs to help secondary school teachers better prepare their students for a range of advanced technical skills, but those programs are not fully developed or implemented at this time.

Wayne County Schools Career Center (WCSCC)

Smithville, Ohio
wcscc.org

Spoke with:

Lynn Moomaw, Director of Operations and Adult Education

Located in northwestern Ohio, Wayne County has long specialized in agriculture and manufacturing, which employ respectively 3.32 and 2.18 times more people than what

would be expected in a location of this size.[38] The school system has been responding to the needs of employers for more skilled workers in the area. The countywide career center enrolls about 750 high school students and 300 adult students. About 100 of these are working toward certifications in advanced manufacturing fields.

Apprenticeship has been a model for workforce development in the county for a long time. However, recently it has become possible for the career center to directly sponsor registered apprenticeships, taking the planning, paperwork, and certification burden off of employers. Currently, WCSCC is helping run apprenticeship programs with 10 employers.

Advisory committees that include local employers are able to help set priorities and curriculum for the system as well as respond to the changing workforce needs of employers. Two parts of WCSCC's curriculum have received positive feedback from employers: their "A-game" soft skills curriculum as well as their membership in Drug Free Clubs of America (drugfreeclubs.com). Being a member of Drug Free Clubs of America allows it to both offer testing services as well as treatment and counseling. Employers appreciate their efforts to help combat the opioid epidemic, and the high job-placement rate is indicative of employers' trust of this program.

WCSCC faces challenges attracting students. Despite recent closures of a few manufacturing factories, manufacturing jobs are still in demand if applicants are prepared with the right skills. They have recently begun hosting "Manufacturing Day" programs at local high schools, in partnership with local employers. This can help open students to the possibility of a manufacturing career and show career pathways that allow students to earn a salary while working and still receive credits toward associate's or bachelor's degree programs.

Indiana University Manufacturing Policy Initiative

Bloomington, Indiana
https://manufacturingpolicy.indiana.edu/

Spoke with:

Keith Belton, Director of the Manufacturing Policy Initiative

Manufacturing Policy Initiative is a program within the Indiana University School of Public and Environmental Affairs. While this program does not directly provide training or workforce development, it conducts analysis and provides recommendations on public policy issues affecting manufacturing in Indiana and the United States.

Its most recent paper, "The Seven Secrets of Germany," takes a thorough look at the workforce development system in Germany and identifies key factors that can be implemented in the United States. One key finding is that Germany's educational system provides significant support both to universities as well as to skilled trades through trade schools and apprentices. This system successfully produces competent, committed workers in manufacturing as well as knowledge-based fields.

38. "Wayne County, OH," DataUSA, https://datausa.io/profile/geo/wayne-county-oh/.

America Makes

https://www.americamakes.us/

Spoke with:

Brenda Vogley, Workforce and Educational Outreach Advisory Group

America Makes is a public-private partnership composed of over 200 member organizations from industry, academia, government, and non-government institutions, working together to innovate and accelerate advanced manufacturing and 3-D printing to increase U.S. manufacturing competitiveness.

America Makes operates a digital storefront, which offers a number of workforce development resources to member organizations. There are links to online training or boot camp programs, which can be administered directly to employees or students. There are links to sign up to in-person training events, generally offered at partner educational institutions. There are also links to ongoing research, market data, and technology roadmaps.

America Makes also operates two physical locations: The Innovation Factory and the Satellite Center. The Innovation Factory is located in Youngstown, Ohio and offers demonstrations, training events and boot camps, and workshop space for meetings for member institutions. The Satellite Center is offered through The University of Texas at El Paso (UTEP) Keck Center. The multidisciplinary research facility is focused on the use and development of additive manufacturing technologies. They offer programs for educating teachers, faculty, and instructors at other institutions to integrate additive manufacturing into existing curricula.

Tooling U-SME: Manufacturing Training Online

www.toolingu.com

Kris Ward, Marketing and Business Development Director

ToolingU is the online training and workforce development program operated by the Society of Manufacturing Engineers (SME). They were one of the founding members of the America Makes network. ToolingU offers online industrial manufacturing training, development, and competency-based apprenticeship programs. Approximately 6,000 companies, including half of the Fortune 500 companies as well as 600 community colleges and numerous workforce development boards, use Tooling-U resources.

ToolingU offers consulting services to companies to help them plan to meet their skills needs and develop workforce training plans. They can use local community colleges and workforce development boards to both upskill incumbent workers as well as recruit and train new employees. ToolingU can help write job descriptions and competencies to make sure companies find the applicants to meet their needs. They also help design the onboarding process and build career pathways for incoming workers. And they can help companies design internal training programs through “train the trainers” courses.

ToolingU offers a broad suite of online training courses. These courses can be used directly by employers for their employees. We also found many educational institutions that use ToolingU courses to supplement their in-person coursework. ToolingU also has instructors available to do on-site training directly for employers.

2 | Findings

Overall, we found that the most commonly mentioned challenge for increasing the skilled workforce in advanced manufacturing centered around negative perceptions of manufacturing jobs among the potential workforce. Many people we spoke with noted how this decreased the available pool of quality applicants, and many efforts they worked on were designed to help combat this perception. We found that apprenticeships are increasingly the preferred model for workforce development, and there are many efforts underway with funding available in this area. Existing training programs, especially those with a short "boot camp" training model, are being remodeled as "pre-apprenticeship" programs. There is an extensive network of stakeholders, including employers; employees; public and private educational institutions; federal, state, and local governments; and public-private partnerships and workforce development boards. We saw the greatest successes in areas where these various stakeholders were aligned on common goals and strategy to pool their resources to provide a suite of training programs that meet employers' needs for a skilled workforce and employees' desires for credentials and good-paying jobs.

Perceptions of Manufacturing Jobs among Potential Workforce

Manufacturing has historically been a source of good, middle-class jobs for Americans without post-secondary education. The United States has long been at the forefront of innovation and technology in the manufacturing sector, from Henry Ford's assembly line to the modern robotics of today. However, even as U.S. manufacturing output has continued to grow, productivity improvements require fewer workers to produce more. Manufacturing employment peaked in the late 1970s and has generally been declining ever since, although in recent years there has been a slight increase in manufacturing jobs. U.S. manufacturers are growing because being close to your consumers is good for business, but they often have difficulty finding the skilled workers they need to meet today's demands.[39]

In our interviews, everyone we spoke with mentioned there is a negative perception of manufacturing jobs, but they were clear that perception did not match the reality of modern manufacturing. "This is not your grandfather's factory" was a refrain heard from

39. Michael Stillwell, "The Future of American Manufacturing," *Popular Mechanics*, May 23, 2018, https://www.popularmechanics.com/technology/infrastructure/a20066511/american-manufacturing/

several people. In our survey, a majority of respondents agreed that it was challenging finding applicants for advanced manufacturing training programs and that many potential students did not know about career options in advanced manufacturing.

Secondary schools in the United States often focus on preparing students for four-year colleges, and in recent years there has been even more pressure to do so. Career and technical education has been declining in emphasis for decades. According to a Brookings report, credits in these kinds of programs fell 14 percent between 1990 and 2009.[40] With so much focus on going to college, manufacturing training programs, as well as employers, have struggled to find a skilled workforce. One instructor spoke of a promising student in one of his pre-apprenticeship programs but then lamented, "He could have gotten an apprenticeship anywhere and be making a good salary. But unfortunately for us, he decided to go on to work on an engineering degree instead."

According to a study by Deloitte and The Manufacturing Institute, fewer than 3 out of 10 parents would encourage their children to pursue manufacturing as a career, and one-third strongly discouraged their children pursuing manufacturing careers, citing job insecurity, weak career paths, and low pay as top concerns.[41] This is also reflected in broad trends in employment: while earnings and benefits for manufacturing careers remain above the national average, total employment remains well below its peak from the late 1970s, and layoffs make bigger headlines in the news than expansions.[42]

Ecosystem of Training and Workforce Development Programs

Within our surveys and interviews, we found a large ecosystem of different institutions that are all involved in workforce development for advanced manufacturing. These include community colleges and technical schools, regional workforce development boards, federal government programs, online-only for-profit training programs, consultants, and maker spaces.

Community colleges and technical schools have served as the backbone of workforce development for decades. There is a wide variety in their structure as well as their approach to local programs. In Indiana, for example, Ivy Tech operates more than 40 locations across the state. This structure allows them to share resources and leverage best practices. In most states, however, there is not nearly as much statewide organization of local community colleges. This can present challenges to employers with a large footprint who want to recruit from different areas since they must develop relationships with many disparate educational institutions.

Regional workforce development boards and associations are a critical component of the workforce development ecosystem. Many of these receive a variety of funding, either through their state, local chambers of commerce, or federal programs. NIST operates a web of MEP programs in all 50 states. These MEPs operate as a public-private partnership, with funding from the federal government as well as private grants and

40. Brian A. Jacob, "What we know about Career and Technical Education in high school."
41. "2017 US perception of the manufacturing industry," Deloitte, June 2017, https://www2.deloitte.com/us/en/pages/manufacturing/articles/public-perception-of-the-manufacturing-industry.html
42. "Industries at a Glance: Manufacturing: NAICS 31-33," U.S. Bureau of Labor Statistics, https://www.bls.gov/iag/tgs/iag31-33.htm.

client fees. As a whole, these organizations help connect employers and their needs to the available workers. They are often leading the work of developing apprenticeship programs with employers in their area.

One of the challenges with this ecosystem is the varied funding sources available for training, both to students and to employers. The main federal programs that help fund training are the Workforce Innovation and Opportunity Act (WIOA) and the Trade Adjustment Assistance for Community Colleges and Career Training (TAACCCT). The Department of Labor has also announced over $95 million in grants for apprenticeship programs.[43]

WIOA was enacted in 2014 as a follow up to the Workforce Investment Act of 1998. It primarily funds the "One Stop" employment and job placement services. The funds are administered through the Department of Labor, but there is significant local control given to administering programs. One Stop locations are required to provide both career services as well as access to training services.

TAACCCT grants are another funding stream provided through the Department of Labor directly to community colleges and technical schools, with $1.9 billion awarded over the past four years. Grants are targeted towards communities and workers displaced because of trade adjustment; however, all 50 states receive funding, and approximately 60 percent of public community colleges receive funding through this program. The broad reach of this funding, with a strong focus on employer-aligned career pathways, provides spillover impacts on all workers.

In recent years, a number of workforce training programs have moved toward online educational models. An example is ToolingU, which provides online manufacturing training. These programs can supplement both traditional classroom training environments as well as meet the educational requirements for a registered apprenticeship program. One of the instructors we spoke with highlighted their partnership with an online training program, noting that it allowed him to focus his time with students doing practical work on the machines.

Online educational models were also a focus for both military and veterans' groups. These service members can earn credentials that enable them to transition into good jobs when they leave the service.

With so many different options for both employers and training programs, we found many consultant services directly involved in this ecosystem. Consultants can help employers navigate the paperwork to apply for funding for registered apprenticeships. Consultants were often closely aligned with workforce development boards or MEPs. Indeed, the MEPs, which operate in a public-private framework and charge client fees to participating employers, sometimes straddled a line between public service and private consultant. We found a perception in this space that applying for certification is complicated and could only be done with some form of outside assistance, usually a consultant. Reducing the complexity and bureaucracy would reduce the costs for employers and help encourage more to participate in certified training programs. In interviews, the public-private

43. "Apprenticeship Grant Opportunities," U.S. Department of Labor.

partnerships were generally seen in a positive light. They can both encourage more participation while still ensuring that these programs are accountable and meeting the goals of public funding.

It was notable that almost everyone we visited operated maker spaces. These were spaces where entrepreneurs and local businesses could access the equipment and expertise of the training center. For a monthly fee, these small businesses could rent space, collaborate with other entrepreneurs, and use some of the workshop equipment for design and prototyping.

Most of the people we spoke with who operated maker spaces noted they were not necessarily a profitable part of their operation. However, they emphasized their importance for the communities and that the benefits were not always directly captured. A large nationwide chain of maker spaces, TechShop, had recently gone bankrupt, but these kinds of spaces are an important public good that can fuel growth for many other businesses. For example, in Pittsburgh, the UPitt MAC is co-located in a space with several small businesses. An example is threadinternational.com, which is producing backpacks made from recycled plastic bottles from Haiti. They were able to access some of the design equipment available through the MAC. Similarly, BoXZY is a small business that is now developing a desktop 3-in-1 machine that functions as a computer numerical control mill, laser engraver, and 3-D printer.

Finally, these maker spaces offered an opportunity to showcase new manufacturing and the kinds of jobs that are available. To the extent there are negative impressions of what factory jobs look like, having these spaces available helps change those perceptions. All of the institutions we spoke with hosted high school students throughout the year to tour and see the equipment. They also regularly hosted other community and stakeholder groups and focused on reaching out to underserved communities, minorities, women, and veterans to highlight available jobs in this industry.

Types of Training Programs

In general, there are several types of instruction offered by educational institutions.

Short, intensive introductory boot camp programs have a history of being an entry to the skills needed in shops on the manufacturing floor. Most programs we interviewed still offered these programs, either for potential job applicants looking to get a foot in the door or for employers who need a quick onboarding process for new hires.

Many programs we interviewed were restructuring these programs as "pre-apprenticeship," and shifting the emphasis into career-track positions. Pre-apprenticeship programs could serve as a screening process for potential employers and could serve as a simplified application process for potential workers. Siemens particularly noted how this model of pre-apprenticeship allowed several local employers to work together to recruit future apprentices.

Related to these boot camp programs were summer camps targeted at high school (and occasionally middle school) students. Several of the organizations we interviewed offered these types of programs, and they noted two key benefits. The first was they help address the negative perceptions of students (and their parents). Students exposed to advanced

manufacturing techniques (as well as introducing them to potential employers) were more likely to consider a career in manufacturing as more desirable. They could also see the benefits of working immediately after graduating from high school, while still having the option (through apprenticeship and continuing education) to continue post-secondary education. The second benefit was helping students get the skills they need before applying for advanced manufacturing jobs. Since many secondary schools have cut vocational and technical curriculum, these boot camps were often the first-time students were exposed to basic machining concepts. They also allowed students to get information on the other kinds of skills necessary for advanced manufacturing jobs, including math and programming, so they could select those courses during the regular school year.

Community colleges were almost always involved in the workforce development programs of those we spoke with, but there were several different approaches. Some community college programs directly worked with employers, while others seemed to take a more passive approach. Most workforce development organizations and MEPs had direct relationships with local community colleges and were often co-located on the campus or in the facilities of a community college. These organizations would often take on the role of working with employers to design programs, but students would ultimately sign up for courses (as well as apply for financial aid) through the community college.

Apprenticeship programs require an educational component, and both employees and employers wanted educational credits to count towards a degree. Under new Department of Labor regulations, a community college can be certified as an Industry-Recognized Apprenticeship Program (IRAP), allowing it to take on the certification requirements on behalf of employers who want to participate in an apprenticeship program but were concerned about the paperwork and regulatory burden.

Institutions that had a lab or workshop usually make this space available for training sessions organized by an employer. However, several mentioned that it could be difficult for an employer, especially a small employer, to fill a class with enough students to make the class economically viable. Nevertheless, these institutions were often willing to be flexible to find an arrangement that could meet the employer's training needs, whether setting up a stand-alone class at a time that was convenient for the employer or rolling the employer's trainees into a larger class with other students.

Almost every institution we spoke with would help connect employers with instructors who could deliver training on-site at the employer's worksite. This practice is advantageous since it allows students to get experience directly on the types of equipment they were working with and could be tailored to the best time for the employer's production schedule. The disadvantage was this type of training could take time away from production, which was particularly challenging for many employers. Most people we spoke with agreed that employers face difficulty finding time in their busy production schedule to train their employees.

Most educational institutions had programs particularly designed as "train the trainers" or for other educators and teachers. Several interviews mentioned this was a key component of improving workforce development overall because instructors at a business could be mentors and help upskill workers at their own workplaces.

Apprenticeships

Apprenticeships were brought up, unprompted and often at the start of our conversation, with every organization we met with. The apprenticeship model has long been a way to join the skilled trades, but recent focus (and over $150 million in grant funding) from the U.S. Department of Labor has increased the emphasis on apprenticeship as a model for increasing skills in many industries, including advanced manufacturing.[44] There are a few key elements that make apprenticeships desirable for employers, employees, and educational institutions.

The first is the ability to work while continuing education. This benefits employees, who do not need to take on debt and can earn a salary while earning a degree. This also benefits employers, who can fill positions immediately and provide training that is focused on their particular equipment or manufacturing techniques. And obviously, community colleges and technical schools appreciate the steady enrollment from apprentices.

The second is the available funding. The U.S. Department of Labor recently announced over $150 million in grants for apprenticeship programs. In addition, there is often a large pool of state and local government subsidies, as well as private sector grants, to help subsidize the cost to employers of taking on a less-skilled employee as well as subsidize the cost of education and training to employees and educational institutions. Workforce development boards and MEPs were often very knowledgeable about available funding streams and tax benefits and could help employers design programs that tapped into these resources in their area.

In our interviews, there were a number of concerns raised with apprenticeship, as well as possible ways to mitigate those concerns.

Employers were often concerned the paperwork or regulatory burden to receive certification would be too high to provide a financial benefit. The certification process is happening both at the federal level, through the Department of Labor and the Department of Education, and the state level, through a patchwork of state agencies and programs. Most local workforce development boards and MEPs (and other consultants) were willing to help employers with paperwork to become a registered apprenticeship, but they would also help an employer design an apprenticeship or upskilling program even if they chose not to become registered. They would highlight that becoming registered not only opens up access to subsidies and grants but also results in credentials (including both journeyperson certification as well as two-year and four-year degrees) for employees so they can more clearly see the benefits of the training. Some programs we interviewed were also hesitant to have too much federal interference in the certification process, allowing local programs the independence and flexibility to design programs that fit the local need and context.

Employers were also concerned about poaching: they would invest money and time into workers, only to have another employer hire the employee as soon as he or she finished the apprenticeship. However, in interviews with many individuals, we found poaching

44. Glenn Thrush, "Amid Worker Shortage, Trump Signs Job Training Order," *New York Times*, July 19, 2018, https://www.nytimes.com/2018/07/19/us/politics/trump-worker-training.html.

was not common. Most apprenticeship programs included a requirement for an employee to stay with the employer for a period of time after the program ended. But even without this requirement, employees appreciated the investment of their employer and felt a loyalty to the company and to the program. Employees appreciated that if they did need to leave an employer, for example for family reasons, they would have a credential that was recognized nationwide. Employees also appreciate that a credential recognized nationwide would have value if they ever did need to move, even if they were not looking to immediately switch to a competitor.

Challenges

We asked all our interviewees about the challenges they face as well as the challenges their students face. Interestingly, they noted that job placement is not a significant challenge: there is such a great need for skilled, qualified applicants that all their programs had extremely high job placement rates. Indeed, several noted that when students did not finish a program, it was sometimes because they had been hired into a job in the industry. Most identified a combination of greater challenges: encouraging employers to participate and finding qualified applicants to begin a program.

Many noted that employers sometimes struggle to participate in workforce development programs. They usually identified a few main causes of this. The first was simply economics and time: many employers, especially smaller businesses, have very lean operations. If they are already operating at full capacity, it was difficult for them to find time to provide training to their workers. The second was a perception from employers that the paperwork involved would be too difficult or take more time than it was worth. With so many different government and private-sector grants available, it is easy to get the impression there is a complicated landscape. The third was a worry that providing training and certifications to employees would lead to poaching from competitors.

There are a few ways the institutions we interviewed are addressing these challenges. The first is a combination of making the economic case for the benefits of a more skilled workforce and being flexible to employers' needs and schedules. Our interviewees noted how important it is to let employers know that an apprenticeship is not only restricted to new hires but can be a model to upskill incumbent workers, even at a small firm. The second is taking the burden of paperwork off employers entirely, or at least providing assistance. Institutions like RCBI or MEPs are often willing to provide direct assistance to employers so they can apply for and receive grant funding toward training or apprenticeships, and they would provide that assistance whether or not the apprenticeship programs were registered. In the most recent apprenticeship initiatives, there has been a focus on this kind of flexibility. It is now possible for another organization to become certified as an IRAP and take the paperwork and certification burden away from the employers. Finally, poaching by other competitors is not nearly as great as feared. Several institutions noted that by investing in their workers, the workers felt a greater sense of loyalty and attachment to the employer.

Finding applicants in general was often mentioned as a significant challenge. There were several reasons mentioned. The first was simply the perception of manufacturing jobs as less desirable. Many high schools are focused primarily on college preparation, so

technical career programs have been squeezed or eliminated. Similarly, parents were often reluctant to encourage their children to pursue manufacturing jobs. This is why most of the institutions we spoke with offered some services and outreach to local school districts, and not just high school career technical schools, but also middle schools and community youth groups. These programs helped stimulate interest in these available career paths and let both students and parents know there are good jobs available that pay decent salaries in manufacturing. Having facilities students could tour and see the machines in action was part of this outreach as well as hosting workshops and summer camps. Some programs also take portable desktop 3-D printers to do demonstration projects in schools.

Of the pool of people interested in this career, the next challenge was finding those applicants who meet minimum technical qualifications. The changing nature of advanced manufacturing means applicants need a blend of skills. They still need the traditional manufacturing skills: the ability to operate a hand lathe or mill, for example. With fewer schools offering technical education or even a shop class, many potential students do not have the basic understanding of how these machines work. Even when something is made on a 3-D printer, it often still requires some time on other machines before it becomes a finished product. However, at the same time, advanced manufacturing jobs also require minimum standards of math and computer proficiency. CNC lathes and 3-D printers need technicians who can competently program or troubleshoot when they break down. Taking measurements, using CAD, and translating that into a design requires a mix of skills and a bit of creativity (and often the potential applicants with that mix of skills are more interested in pursuing a four-year degree).

Many institutions also mentioned the challenges of poverty, transportation, and the opioid epidemic among their pool of potential applicants. The UPitt MAC recently moved into the Homewood neighborhood, an economically depressed area of Pittsburgh. However, upon graduation, these individuals may not be able to reach jobs that may be in another part of the region due to a lack of transportation or they may have difficulty securing or affording childcare. RCBI, located in West Virginia, also specifically noted the challenges of transportation and that students sometimes drive an hour or more from other parts of the state to get to training facilities or employers. RCBI is also situated in a region that has been hard hit by the opioid epidemic, and employers are often reluctant to hire workers with past drug use. RCBI has helped facilitate drug testing for potential applicants, and their pre-apprenticeship programs can help serve as a screening process for future employers.

Additive manufacturing and 3-D printing are one set of skills that employers are hiring for, but few if any employers are hiring workers that specialize in only those skills. Most advanced manufacturing employers are looking for employees who can work in a shop across a range of different types of equipment. 3-D printing is often a key element in the design and prototyping phase of product development, even for non-manufacturing firms (for example architectural firms that want to create a model).

However, while 3-D printing has moved well beyond simple prototyping, its use has generally been limited to producing unique parts in single or small batches. A 2017 report by the CSIS Scholl Chair noted that additive manufacturing is not likely to replace traditional manufacturing in the near term, in part due to the fact that “the technology

does not currently scale well, and conventional manufacturing enjoys a significant cost advantage in high-volume manufacturing."[45] Nevertheless, additive manufacturing still has enormous potential. One study estimates that it will create three to five million more jobs[46] and add $600-900 billion in annual economic growth in the next ten years.[47]

This creates challenges for training programs that want to focus on additive manufacturing skills or with advanced manufacturing skills in general. There is not enough demand at this moment to justify a narrow-focused program. But a program that tries to meet the needs of all employees and employers in an area may end up being too generic. Generic programs are often less helpful than specific on-the-job training because skills can be unique to the production process and equipment of an employer.

45. Scott Miller and Daniel G. Sofio, Additive Manufacturing: A Guide for Policy Makers (Washington, D.C.: Center for Strategic and International Studies, 2017), 3, https://csis-prod.s3.amazonaws.com/s3fs-public/publication/171220_Miller_AdditiveManufacturing_Web.pdf?LTl3w2weL0GcF1EM_JQy2HcsqBDJG_dv.
46. HP and A.T. Kearney, *3D Printing: ensuring manufacturing leadership in the 21st century* (HP and A.T. Kearney, 2018), 18, https://www8.hp.com/us/en/images/3D_Printing___Ensuring_Manufacturing_Leadership_in_the_21st_Century_tcm245_2547663_tcm245_2442804_tcm245-2547663.pdf.
47. Ibid., 15.

3 | Recommendations

Overall, preparing workers for advanced manufacturing jobs will require combined efforts across multiple stakeholders, including multiple levels of government as well as private parties. Following are some recommended useful steps:

Youth Education and Engagement

- *Engage students at a younger age.* During our interviews, several organizations highlighted the boot camps and summer camps they host aimed at high schoolers or even middle schoolers. We recommend more organizations, whether local government workforce development agencies, community colleges, or online learning portals, consider outreach to this younger audience. As stated, these programs encourage students to explore at a younger age the possibilities of an education and career in advanced manufacturing, exposing them to options beyond a four-year bachelor's degree. Exposure at a younger age also serves to combat negative stereotypes of manufacturing as dirty, dangerous, and career limiting-both for the student and their parents.

- *Expand and improve vocational training education at high schools.* Jobs in advanced manufacturing require a mix of skills, including basic machining, mechanics, and computer coding. Students can be inspired by the opportunity to make physical objects, and that inspiration can be beneficial to whatever fields students pursue.

- *Make clear that STEM education is not only for college-prep.* Several organizations we spoke with emphasized that many potential students simply lack the mathematics, technology, engineering, and problem-solving abilities to operate advanced machinery. While this touches on larger issues in our public education systems, we recommend school districts work toward teaching all pupils these skills, which are necessary not just for advanced manufacturing but many jobs of the future.

- *Expose students, parents, guidance counselors, and administrators to advanced manufacturing jobs as an attractive career option.* Career pathways should emphasize the variety of paths as well as the variety of jobs available within the industry; they should demonstrate the opportunities from these skills. Students should know they will not be limited to only one type of employment or only one company but that these skills are flexible and open up many opportunities across multiple industries.

Guidance counselors and administrators need to better understand manufacturing technologies and the training programs available in their own institutions and communities so they can actively support those programs and make sure they are integrated into their schools' programs and schedules rather than just tolerating them, and so they can encourage students to take advantage of them.

- *Reorient and rebrand manufacturing.* Efforts should be made to change the conversation around manufacturing careers away from the narrative of a dying and dirty industry not well aligned with our digital future. Manufacturing companies should do more to highlight the high-tech and cross-disciplinary skills students can learn, the advanced machinery they will use, and the lasting job prospects in this field. Additionally, manufacturing should be pitched as a creative, hands-on career that creates physical things. The skills here are part of an ecosystem of digital skills, applicable in coding, machining, DIY, human-centered design, and social impact design. Overall, advanced manufacturing is an opportunity to do hands-on work, design, and create.

Lifetime Learning

- *Create multiple "on-ramps" for adults continuing education and career change.* Older models of workforce development anticipate a young worker will continue with a single career, often at a single employer. Younger generations, however, often anticipate they may change employers and careers multiple times throughout their lives. Educational institutions need to identify "on-ramps" into advanced manufacturing jobs as well as "off-ramps" for people who might be looking for their next career move. Lifetime learning across multiple employers and career paths will require socializing the costs to allow more modularity and mobility.

- *Accommodate and promote work-study arrangements.* Educational institutions, including high schools and community colleges, must make additional efforts to accommodate students with full-time jobs, both by making schedules flexible and using distance learning, particularly to reach students in rural areas. At the same time, employers must recognize the value of upskilling their incumbent workforce: taking time out of the production schedule in the present will lead to productivity gains in the future. Developing programs to train more trainers can pay long term dividends as well, as students can become teachers within a company, increasing the impact of a skilled workforce.

- *Apprenticeships can be a good model for employers and employees to collaborate in lifetime learning.* National standards should be developed and broadly adopted, led by industry, government, labor, and education stakeholders. Apprenticeships should result in modular, portable credentials for employees and should be subsidized to improve access for employers and their employees.

Local Governments and Community Organizations

- *Provide wrap-around, community-focused support services.* Several institutions and organizations we interviewed offered services beyond training courses in advanced manufacturing. These included transportation supplements and drug testing. In many cases, there are significant barriers to entry for potential successful students

and employees. Many come from lower income, underserved communities whose access (physical or financial) to transportation can be difficult, whether it is a student traveling to a training program or a successful graduate going to a potential employer or worksite. For programs struggling with cost-effective class sizes, transit benefits may allow wider geographic sourcing of students as well, enlarging class sizes. Both the UPitt MAC and the Ohio MEP seem to have seen some benefits from transit support. Programs may want to consider other services such as childcare support, housing support, or medical support to engage a wider diversity of students.

- *Help address the opioid epidemic.* The opioid epidemic remains a significant issue in many communities across the nation, especially in economically depressed regions. The UPitt MAC program and the Wayne County Schools both mentioned offering drug testing and even counseling. Training-level drug testing removes the expensive and time-consuming burden on employers of drug testing, in addition to savings on onboarding and training time for an employee who might later be let go for substance abuse reasons. It also is a boon to training centers, creating trust and a reputation with potential employers since they know graduates from these institutions will be more reliable.

Overall, programs that offer support services can provide a threefold benefit. First, they provide an opportunity to underserved communities, both in training and accessing steady, well-paying jobs. Second, they provide employers with screened and reliable workers. Finally, they help training institutions build a relationship of trust and a reputation for reliability for employers, students, and their local communities.

Maker Spaces

- *Expand access to advanced manufacturing tools and technology for general use.* Many educational institutions already own labs with these types of equipment. We encourage the wider adoption of maker spaces as a gateway opportunity to engage and educate curious individuals and companies on the possibilities of advanced manufacturing. Several visited programs hosted these maker spaces at their facilities for general use.

- These spaces offer access to advanced tools and technology like 3-D printers to small businesses, entrepreneurs, and the general public, often for a fee but sometimes for free. The Robert C. Byrd Institute in West Virginia; the Center for Manufacturing Innovation in Greenville, South Carolina; the UPitt MAC program; and Cuyahoga Community College in Ohio all mentioned that they have these spaces.

- Maker spaces are a low barrier entry point for interested individuals and organizations to engage with advanced manufacturing technology and concepts. During our interviews, we observed a variety of users participating in these spaces, often out of their own curiosity and outside of any formal training curriculum. The maker spaces provide an opportunity for training institutions to showcase the new technology and involve interested parties. Maker spaces can serve to educate people on the technology itself, the training required to use it, and the employment opportunities that exist with training on these machines.

- Maker spaces also serve as anchor points which bring together entrepreneurs across many industries. Economists have long noted the benefits of clustering in industries: having many individuals in close proximity can allow them to share ideas and best practices. It also allows entrepreneurs and small businesses to take advantage of economies of scale that are typically only available to larger companies. Threading together these spaces in a cohesive way as a gathering place for industry should pay dividends in the future.

Federal and State Governments

- *Streamline and simplify the bureaucratic process for apprenticeships.* Many programs noted that they assist employers in applying for funding or grants to engage in worker training and registration of employers as certified apprenticeship programs. Many employers, however, found the entire process of applying for funding and certification to be burdensome, confusing, and time-consuming. While we commend the educational institutions for providing the expertise to employers to navigate this process, the system should be simplified to encourage further participation by employers themselves. Employers should not have to rely on institutions or consultants to navigate this process and successfully apply for funding or certification. We recommend that government agencies engaged in grant allocation and program certification analyze how they can better streamline the process. By lowering this burden, employers, workers, and educational programs can better access the financial support to produce better training and therefore better jobs.

- *Evaluation must be a cornerstone for all government funding programs, with clear goals and standards from the outset as well as simple and publicly transparent tracking of impact and effectiveness.* Evaluation of funding streams must become standard practice for federal and state governments. Programs should be designed with evaluation criteria as a priority, not an afterthought. Evaluation should not simply be another layer of the paperwork reporting burden but must be seamlessly built into the funding. Programs which are successful at meeting goals should be expanded, while programs that face challenges should have the flexibility to be redeveloped.

- *Use the federal workforce and military to lead by example.* The federal government directly employs 2.8 million workers, and the U.S. Armed Forces include 1.3 million active service-members and 800,000 reserve service-members. From one perspective, the U.S. military is among the largest workforce development training programs in the world. Upskilling and reskilling these millions of employees, ensuring they have access to training and lifetime learning, can stimulate the private sector. It can be particularly beneficial for active service-members, who can learn skills that are useful while deployed and will translate directly into employable fields when they separate from active service.

4 | Conclusion

This study demonstrated that there is, first, a significant amount of activity across the country on advanced manufacturing workforce training, with many people foreseeing the importance of training in skills of the future and actively working toward equipping the working public with these tools. Second, the pathway to a successful training program lies in more than just the curriculum and direct manufacturing training. Often, adjacent services like substance abuse support, transportation subsidies, and medical assistance can be the deciding factor in creating a successful graduating class that finds employment. Effectively educating the workforce will require efforts to creatively target not just the core post-high school demographic, but also younger students and older workers, whether that means introducing advanced manufacturing as a viable career option or retraining workers midcareer in new techniques. Finally, it is clear that further in-depth study of this issue will benefit the future workforce and continued economic growth.

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