Chapter 3

The Role of American Universities in Advanced Manufacturing

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Introduction

American HE (higher education) has long been involved in research about the technologies behind what is known as the 4IR (Fourth Industrial Revolution), but has also been divorced from the 'industrial' part of that revolution. Thus, while American HE has supported extensive technology research in such areas as IT (information technology), advanced materials, and AI (artificial intelligence), it has not been nearly as involved in research on the related manufacturing technologies and processes. However, stagnating industrial productivity rates and a sharp decline in manufacturing employment forced the US, starting in 2012 to consider what has been termed 'advanced manufacturing.' The solutions considered were oriented towards applying the nation's capabilities in technology innovation to its manufacturing sector. Since research universities in the American innovation system play an important role in technology research, these schools are now starting to be brought into this effort to upgrade manufacturing. How did this disconnect between university research and manufacturing technologies and processes come about?

The advent of large-scale, federally funded research during World War II, which continued in the post-war period, enabled the US to build a network of strong, research-based universities. Much of this research enabled follow-on technology development, as the US was able to orient its economy around an innovation-based growth model. However, because the US was the unchallenged leader of mass production coming out of World War II, it simply assumed that this production leadership would continue while it was creating its research and development support mechanisms (Bonvillian & Singer 2018:34-35). This federally funded R&D (research and development) was directed towards research and focused technology development, but not towards manufacturing innovation. R&D is a preliminary stage on the path to innovation, which embodies not only the R&D but the full implementation of technology into societal use. Manufacturing largely was left out of both federally-funded R&D as well as follow-on innovation efforts.

Although a succession of global manufacturing challengers arose in recent decades, including Japan, Germany, Korea, Taiwan, and now China, the US innovation system never took up the challenge, causing those nations to make significant inroads on the US share of global production. The strong university research system was simply not applied to manufacturing technologies – university research and manufacturing technologies were disconnected. Many quality manufacturing jobs began to disappear as global competition rose and US multinationals used a distributed production approach to shift production abroad. However, when China passed the US in manufacturing output in 2011, and a major social disruption developed for the American working class, the realisation began dawning among policymakers about the consequences of ignoring production. The Obama administration initiated an innovation-oriented policy approach to manufacturing and began enlisting American research universities in the cause. This started a process to better connect production and the still strong US innovation system with universities playing a major role.

This chapter reviews the nature of the production challenges facing the US, including the widespread social disruption that came from the decline of its manufacturing sector and the important role of production in innovation capability. It then turns to the new innovation policy approaches that the US adopted for manufacturing in response to the challenges starting in 2012. At the forefront of that response is a new role for US universities in production innovation. The US university role since the post-war has been in basic research and education for the liberal arts, but universities are now helping to lead the new AMIs (Advanced Manufacturing Institutes) and gradually expanding their work on manufacturing-related R&D. However, there is a parallel issue that they must also address: The talent base for innovative manufacturing universities is not only for research, as education remains a primary function. In addition to research, they are starting to work on the related challenge of new manufacturing workforce education. The manufacturing challenge is requiring universities, therefore, to undertake more applied work in manufacturing technologies, as well as more workforce education for those new technologies. Pending manufacturing initiatives are now pushing universities in those directions.

The American Manufacturing Challenge

Manufacturing decline has been linked to extensive social disruption in the US during the first two decades of the 21st century. The decade between

2000 and 2010 was a painful one for US production: Manufacturing employment decreased by 5.8 million jobs – by almost a third – from 17.3 million to 11.5 million. By 2015, it had only recovered to the 12 million job level (Manufacturers Alliance 2018). Manufacturing, historically, was a very important middle-class pathway for high school educated males, but that group has been experiencing a very significant labour non-participation rate in the US – the share of these men of prime working age not working at all, reached 18% in 2013 (Pew Research Center 2014). Importantly, the median income for men with less than high school educations decreased by 20% between 1990 and 2013 (Kearney, Hershbein, & Jacome 2015). There is also a growing income split between college and non-college educated, leading to a major rise in US income inequality. Therefore, restoring manufacturing was a frequently cited subject in the divisive 2016 presidential election and thereafter. In a country that prided itself on its social mobility, this was a clear signal of a loss to middle-income ranks, of growing social inequality, and a post-industrial backlash. Below, we will review key problems in the US manufacturing system that helped create these issues.[1] Then we will turn to the questions of whether advanced manufacturing can speak to it and what the university role could be.

Problem #1: Low Productivity

Although the US lost nearly one-third of its manufacturing jobs in the 2000s, economists thought its manufacturing output was holding firm. However, on re-examination, experts found that it was in decline in some 16 of the 19 manufacturing sectors measured. Because output is a component of productivity, it meant limited productivity gains. Therefore, the US' overall productivity from 1995 to 2005 was 2.5%, yet from 2005 to 2015 it was in the 1% range (BLS 2018, 2019; cf. also Houseman 2018). Since investment in capital and plant can help to drive productivity, this meant that these numbers were down as well. The US has also been running a staggering trade deficit in manufactured goods of some $900 billion a year – an unprecedented level (Statista n.d.). This includes a $190 billion deficit in advanced technology goods (BEA 2021). The job loss data cited above were not due to productivity advances, it was due to a hollowing out of US manufacturing, largely due to international competition, particularly from China. The low productivity numbers are a signal of the limited entry of innovation into the production. Since one key arm of the US innovation ecosystem is university R&D, it is also a signal of the manufacturing-university disconnect.

1 These problems are discussed in more detail in Bonvillian and Singer (2018:1-100).

Problem #2: A Thinned-Out Manufacturing Ecosystem

The US used to have firms and supply chains in manufacturing that were very vertically integrated, but the prevailing financial model emphasised short-term, quarterly returns. This led manufacturing firms to reduce risk through a focus on their core competency which, in turn, led them to go what was called 'asset light.' The IT revolution, with programmed specifications tied to programmed machines, enabled these firms to delink production from design. The financial pressure and the IT capability led to massive outsourcing and offshoring of production. Additionally, the US closed over 60,000 factories in the 2000 to 2010 period (BLS n.d.). The US has therefore been thinning out its manufacturing ecosystem. The shared assets in the manufacturing system and training, bringing best practices to suppliers, declined. It is therefore thinner out there – there is less in the ecosystem. The small and mid-sized companies in the US system, in Suzanne Berger's terms, are now more 'home alone' (Berger 2013). This 'home alone' problem has many elements, but it is also a signal of the disconnection between university research and manufacturing.

Problem #3: Manufacturing Scale-Up

While the US has many industrial sectors, there are essentially three kinds of manufacturing firms. The first category is large multinationals. They are global and can get production efficiencies by producing in lower-cost countries, where they need to be anyway to participate in global markets. These firms are generally doing well, although the firms have been increasingly producing abroad with consequences for US employment and production capability. However, there are two more vulnerable sectors. The second category is 'main street' firms – the SMMs (small and mid-sized manufacturers) that produce slightly less than half of the US manufacturing output. There are about 250,000 of these SMMs with under 500 employees. They tend, by nature, to be thinly capitalised, and are risk averse to survive. They do not perform science and engineering-based R&D, so they have limited access to innovation, although they can be innovative about adapting their products. Starting in the 1980s, they fell well behind larger US manufacturers in productivity advances (Helper & Mahoney 2017). While there are innovative firms in the mix, as a group they are falling behind in manufacturing advances. Yet, because they account for so much output, too often they are a drag on the overall system. The third category is entrepreneurial start-up firms that make something. The US has had a strong emphasis on such start-ups as a way to bring innovation into its economy and developed a strong system of venture capital to back them. These firms do well until they need to scale up for production. Because the venture capital system in the US is now overwhelmingly focused on software, biotech, and service firms for their short term return window, financing for start-up scale-up is largely unavailable for new manufacturing firms (Bonvillian & Singer 2018:194, 185-215). They are too risky and cannot get to significant production within the necessary five to seven year window. These firms are therefore not scaling up, limiting the innovative firms coming into American manufacturing. If they do scale-up, they must turn to contract manufacturers and prototypers abroad, particularly in China. Since many US start-ups emerge from university research, this is another signal, too, of the university-manufacturing disconnect.

Problem #4: Seeing Manufacturing as Part of Innovation

The US has not pictured manufacturing as part of innovation. It thinks of R&D as innovation, but this is a fragmented perspective. In fact, innovation really is a system from early-stage research through the production function. Production is the enabler of what economists call 'increasing returns in an economy.' While services scale slowly because they tend to be more face-to-face, manufacturing is the scalable factor, which can scale quickly through mass production technologies. It is a foundational societal wealth creator. Treating production as a critical element that has to be connected to our innovation system is therefore critical, otherwise there is a risk of innovation erosion.

Back in the post-war period, when it was building much of its innovation system, the US would both *innovate here and produce here*. As a result, it got the full spectrum of gains from both sides in our economy. Then, largely through digital technologies, it figured out how to *innovate here and produce there*, achieving distributed production (Bonvillian & Singer 2018:57-58). However, for many products, the tie between innovation and initial production is very tight. Dense feedback loops are needed for product design. This initial production requires very creative engineering and design which is very much part of innovation, particularly if one is focusing on bringing out a new technology advance. However, if one shifts production, in many cases the innovation capability has to go with it. For example, a small firm may attempt to shift its production to a contract manufacturer in Asia to reduce its cost and risk. It does the initial design in the US, then sends that design to Asia where it is produced. However, then comes the time to do the incremental improvements. The design team has to go live with the Asian producer because it needs to be close to the actual production process.

The risk here for the US manufacturers that shifted their production capability, is that the innovation capability may have to follow production. The result is a growing problem for the US: *Produce there, innovate there*. If innovation is the US' strong suit, then this is a genuine issue for the future of its innovation capability: If important innovations have to follow production, this endangers the core innovation strength. Since universities are a core element in the US innovation system, this has important implications for the future of university R&D as well, and speaks to the need to integrate them better into the production system.

Problem #5: Lessons from Germany

Most people in the US thought it had to lose manufacturing jobs to low-cost producers in Asia because it was high wage. Germany stands as alternative model because it has a much higher manufacturing wage than even the US. Yet, Germany is running a massive manufacturing surplus, including a manufacturing surplus with Asian nations. What is Germany doing right – are there some lessons for the US to learn?

Just because the US is facing low-wage competitors, does not mean that it has to give up on manufacturing. While 8% of the US workforce is in manufacturing, 20% of the German workforce is. Germany created and retained a deep ecosystem for its manufacturers, small and large – they are not home alone. There is an extensive collaborative R&D shared by industry, government, and engineering universities around new manufacturing technologies and processes through a network of over 60 Fraunhofer Institutes throughout the nation (Bonvillian & Singer 2018:178-183; Fraunhofer-Gesellschaft. n.d.). There is also a famous shared training system, for its workforce through apprenticeships. Its manufacturers also have ways to link their supply chains together in a collaborative way for rapid scale-up.

Germany is a very different country than the US and only some of its approaches are suited to replication. Their workforce training system is difficult to adopt, although modified apprenticeships work, and the Fraunhofer Institutes could be adapted, as will be discussed below. These would work to integrate university engineering research into their production system.

Problem #6: The Hourglass

Envision an hourglass which we will use to describe the manufacturing system (Bonvillian & Singer 2018:59-63). On the top globe of the hourglass where the sand flows down towards the narrow neck, are resources, suppliers, components, and R&D. The narrow neck of the hourglass is the production moment. In the neck are 12 million manufacturing jobs and over 250,000 firms. Then, flowing out of that production moment is the bottom globe of the hourglass which contains all the distributions, sales, repairs, and lifecycle industries that support the product. The production moment is the smallest part of the hourglass. The firms in the upper globe that provide resources, supplies, components, and R&D are a much larger part of the economy, as are the firms and jobs in the bottom globe with distribution, sales, and repairs. All of these elements and firms make up a manufacturing system. Then, throughout the hourglass are value chains of firms – the links between the firms in all parts of the hourglass. If we snap the narrow hourglass neck at the production moment, we disrupt the manufacturing system. Snapping our production capability, snaps the value chains of firms. Although individual firms are disrupted, the bottom globe of the manufacturing hourglass can be restored when outsourced goods are imported. However, the linked firms in the production neck and the top globe of suppliers and the scientists and engineers in the R&D system are not. When the production firms end, their work ends. The R&D part is particularly problematic, since the manufacturing industry supports 60% of the US' R&D. Therefore, when you buy the Hyundai, not the Chevy, it is impactful, and the Hyundai displaces the Chevy and its the network. The decline of US manufacturing has meant snapping very significant parts of these manufacturing value chains, affecting not simply the production firms themselves, but the networks of firms they are connected with. The impact of manufacturing decline has been widespread. Universities, as part of the innovation system, are starting to feel these effects as well.

Is there a way out of these challenges? Could the US relink production and innovation? Would advanced manufacturing be a way of rebuilding these value chains? Is better integration of university research into the production system part of the answer?

Manufacturing Innovation Policies

While the US led in the creation of interchangeable machine-made parts in the 19th century and applied those technologies to enable mass production, which this country has dominated in the 20th century, it has not focused its innovation system on manufacturing processes and technologies. While this system has emphasised development of areas such as aerospace, computing, the internet, and software, there has not been comparable R&D support for manufacturing. As noted at the outset, the US has set up much of its innovation system in the period following World War II. At that time, it dominated the world manufacturing capacity and output. It therefore focused its R&D system on areas that needed more attention, basic research, and new technology development. In contrast, Germany and Japan, rebuilding their economies after the war, focused on what can be called 'Manufacturing-Led' innovation (Bonvillian & Weiss 2015:184-185). Subsequently, Korea, Taiwan, and now also China adopted a similar manufacturing focus. China has already passed the US in manufacturing output in 2011. This prompted the US in recent years to consider a new effort on technology and process development in production. Facing competition from lower-wage and lower-cost competitors, improved manufacturing productivity, while efficiency appeared to be an answer.

There appears to be new manufacturing 'paradigms' potentially at hand that could play this role. Scientists and engineers advise that advances in fields like the following could be achievable:

- *Digital production* – the acceleration of IT intensity in manufacturing, including a mix of advanced IT, radio frequency identification, and sensors for each element in the production process to become 'smart,' from resource through production through product life cycle, with new decision making tools from BDA (big data analytics), and with advanced robotics, supercomputing, and advanced simulation and modelling.
- *Advanced materials* – the ability to design all possible materials with designer features, then fitting new materials precisely to product needs for strength, flexibility, weight, and production cost. In addition, evolve new biomaterials from synthetic biology and explore biofabrication.
- *Nanomanufacturing* – fabrication at the nano-scale and the ability to imbed nano-features into products to raise the efficiency and performance thereof.
- *Mass customisation* – production of small lots at the cost of mass production, for example through 3D-printing/additive manufacturing, where products can be fabricated in highly complex forms and tied to computerised production equipment (Bonvillian & Sarma 2021:80-81).

This is only a partial list. Advances in photonics, composites, new chemical processing, flexible electronics, advanced fibres and fabrics, cyber security, power electronics, and other areas should also be considered.

If the US needs new production paradigms, there are gaps that must be filled in the innovation system to realise them. As noted, the US' R&D remains strong but one gap is that it lacks an R&D effort organised around the advanced manufacturing challenges (Bonvillian & Singer 2018:34-35). University R&D, in particular, is disconnected from production. Most of the potential paradigms need R&D input, but both R&D and implementation also require corresponding technology strategies, a second gap, developed jointly by industry, government, and university experts.

In addition to manufacturing R&D, tied to collaborative technology strategies that include applied work at universities, a third gap concerns workforce education. The advanced manufacturing technologies will not be adopted unless the workforce is ready to do so. A new training effort for advanced manufacturing is therefore required. Reports in 2012 and 2014 (PCAST 1972, 2014) by a task force of leading companies and technical universities named by the President – the AMP (Advanced Manufacturing Partnership) – led to the formation of 16 AMIs, to fill a fourth gap to help implement technology development and to support workforce education. These have been formed around technology fields as listed above. This overall effort to develop advanced manufacturing tried to speak to the six problem areas identified above.

While US universities have historically not been significantly engaged in manufacturing technology and process development, they have performed a diagnostic role in identifying these problems in recent years, helping to foster a series of reports and studies. These reports include Berger (2013) and the National Academy of Engineering (NAE 2016; cf. also reports noted in Bonvillian & Singer 2018:303). The President's AMP, which advocated advanced manufacturing policies in its 2012 and 2014 reports, included six presidents from leading US universities.

The US borrowed its institutes from the German Fraunhofer Institute model, modifying it to fit different US circumstances and needs. The institutes are reaching nearly every state in nearly all of the new technology areas listed above (Manufacturing USA 2020). They are supported by the federal defence, energy, and commerce departments and are cost-shared by industry, state, and federal governments. Each institute is formed to pursue advances in a particular advanced technology area that could be transformative of manufacturing technologies and processes, such as robotics, additive manufacturing or digital production. Institutes attempt to deal with the gaps in the innovation system by

- connecting small and large firms to restore the thinned-out ecosystem;
- relinking innovation and production in collaborations between firms, universities, and government;
- pursuing production innovations to grow efficiencies and productivity;
- providing shared facilities for scale-up; and
- collaborating with firms and education institutions to build a skilled workforce to implement and disseminate advanced production technologies into companies.

The federal government agencies funded each institute at between $50 and $100 million for five years. Each is a non-profit consortium, typically with over 100 participating firms, universities, community colleges, and state and local government agencies. The institutes were formed, starting in 2013 and are making progress deploying these features, which address key structural issues in American manufacturing. The institutes have two underlying missions behind these points: Support applied research advanced manufacturing technologies in the technology area each institute focuses on, and support workforce education – both new content and delivery systems – in their technology field. However, the institutes have faced a limited timetable of federal government support because they initially had five-year terms. Yet, the structural problems are longer term and require longer term leveraging from federal investments, so the agencies are gradually responding by extending support by various means. Despite this longer term funding problem, institutes have been overall quite productive in advancing new technologies and workforce programmes. At stake is the industrial base needed if the US is to have sustained technology leadership.

The University Role in Advanced Manufacturing Technology Development

Industry is only one actor. Locked in worldwide competition, it cannot undertake the risk or long-term investment to generate all of the new technologies and skilled workers required. Instead, a system was found to be needed where a connected network of firms, universities, labour, governments, as well as national and corporate labs together could nurture the next generation of production technologies, processes, and education infrastructure. Again, the market alone will not support efficient levels of investment in these networks, often called a 'manufacturing ecosystem' or 'the industrial commons.' The institute model is designed for the problem of getting to advanced manufacturing, with each institute organised to advance a specific new manufacturing technology, although the size of the overall effort requires scaling them up with additional funding. What will the university role be in this effort?

Since World War II, when the federally-funded research university approach was first adopted, these schools have supported federal agency-sponsored R&D. The federal government has obtained an enormous amount from this approach, with university research often providing the foundational breakthroughs that applied research built on for subsequent technology advance.

However, as noted above, agency support for manufacturing R&D has been a missing piece in the puzzle of the American innovation. This gap underscores a need to open up R&D funding to manufacturing. The new AMIs are an initial step towards meeting that need. They work not at basic research but at what is known in the US as Technology Readiness Levels four to seven of applied research through technology development stages. As part of this approach, 'hybrid' models are needed, where both university research teams and industry, particularly smaller, entrepreneurial firms, are engaged in R&D projects. This hybrid approach has been a hallmark of the DARPA (Defense Applied Research Projects Agency) (Bonvillian, VanAtta, & Windham 2020:101). The approach accesses the out of the box ideas that can emerge from university research, and ties them to companies' expertise in shaping technology development to bring it to market.

Institutes are a start towards the technology development that will be needed for advanced manufacturing, although a larger scale of R&D will be required. Manufacturing is a $1.2 trillion dollar sector in the US, while the total federal cost share of the 16 manufacturing institutes is around $300 million a year. It is hard to achieve a tech revolution on the cheap, therefore other federal R&D programmes will be needed to support these efforts.

Meanwhile, universities have begun to work on manufacturing institute-funded R&D, working with companies. Because only quite limited federal R&D has been available for manufacturing in the past, this is a new research opportunity for a number of schools. However, universities have been working on the earlier research stages of areas relevant to manufacturing such as robotics, AI, and advanced materials, whereas this foundational work can translate into more direct work on manufacturing and engagement with the institutes. Thus, engagement with institutes can open up new more applied research opportunities for universities with funding through the institutes. The institutes have a deep industry involvement and leadership but are required to be led by non-profit entities. Often universities are playing that convening role and every institute has a strong involvement from regional universities, where they are undertaking not only research but helping to organise the technology agendas of the institutes.

For example, Carnegie Mellon University, which has been a leader in robotics research, led a consortium of companies and universities to compete for and form the ARM (Advanced Robotics for Manufacturing) institute which includes 270 robotics companies, other universities, state economic development agencies, and community colleges (ARM n.d.). Carnegie Mellon contributed $50 million in cost share towards the institute and is now a participant in ARM's research and workforce education projects as well as supporting the administration of the institute. Another example is MIT (Massachusetts Institute of Technology), which led the consortium in creating one manufacturing institute in advanced fibres (AFFOA n.d.; Bonvillian & Singer 2018:158-163), has been leading the workforce education part of the institute in photonics (AIM Photonics Academy n.d.), and participating in three other institutes. A third example is the University of Tennessee and the federal energy laboratory it oversees, Oak Ridge National Lab, being a leader in the IACMI (Institute for advanced composites manufacturing innovation) (IACMI n.d.; Bonvillian & Singer 2018:153-158). Many other universities are now similarly engaged.

Manufacturing, however, is not yet a significant research niche in university research. Two universities, the Georgia Institute of Technology (Georgia Tech n.d.) in Georgia, and Clemson in South Carolina (CUCAM n.d.), are exceptions. They have significant advanced manufacturing research technology centres, with manufacturing research in advanced production technologies, as well as growing education programmes in manufacturing. Both these universities are in states with expanding manufacturing sectors, and the university centres collaborate on R&D with area manufacturers. Both universities also participate in various manufacturing institutes. If federal research in manufacturing grows, more university manufacturing technology centres could evolve similar to the programmes that the Georgia Institute of Technology and Clemson have built.

The University Role in Manufacturing Workforce Education Programmes

The US was the first nation to develop mass HE programmes and used these as an engine for economic and social mobility. A college degree is now the key differentiator for economic wellbeing (Golden & Katz 2008). However, HE is also a complex, established 'legacy' sector, reluctant to change and adopt its existing operating modes to fit new needs (Bonvillian & Weiss 2015:96-112). Although its existing degree credentials are largely disconnected from actual job skills, it has become a default credential for employers because there are no others that are as widely accepted and used. But although the degree is the crucial credential for employment, the content of what is being taught largely does not reflect what the employers are now seeking.

Colleges and universities are now finding themselves in a box (Bonvillian & Sarma 2021:118). Clear trends in the workforce show that ever-higher skills – called upskilling – particularly with the entry of ITs, are being required for success in the workforce. The achievement of HE is now critical to finding quality jobs, and the jobs for those with lesser skills are in decline. Within HE, the four-year college degree is increasingly the critical achievement; the two-year associate degree is now required, while the pressure, as the employment data show, is increasingly towards the four-year degree. While the high (secondary) school degree was long the acceptable basic credential, that has now been displaced.

Yet, universities as legacy institutions have been ignoring these workforce developments, maintaining their own separate traditions of what they have taught, largely avoiding more workplace-related content. However, now pressure for workforce credentialing is starting to reach colleges and universities. Their education generally does not reflect career needs, and the capabilities they teach are not particularly well-tied to competencies needed in workplaces. They appropriately defend their liberal art traditions, and these are important ones, but that does not mean they cannot offer more career-related skills in addition. Their degrees are now the determinant, *de facto*, of workforce success, but these degree credentials are not well-linked to workforce realities being taught. The result is a growing sense of frustration for students, employers, and the public.

What could universities do to better prepare its workforce for advanced manufacturing in particular? (Bonvillian & Sarma 2021:127-129). Universities need to add content to their curriculum for the advanced manufacturing technologies, including the technologies delineated under heading 3 above. To summarise, universities can play a key role in organising a better delivery system for workforce education across education institutions and for employers, in developing online course materials and platforms where they can be offered, in delivering courses and content to meet higher end manufacturing technical education, in developing lifelong learning programmes, and on improving the quality of teaching and education in teaching technical material.

For example, the development of education content for higher end technical and engineering skills will likely fit a university role, while technician level content development will likely continue to be the role of America's system of two-year community colleges, as well as employers. The actual delivery of technician content will similarly belong more to community colleges, while higher end technical skills will be a college or university role. However, in new, advanced technologies like digital production or the IoT, the content will overlap, with engineers and technicians needing to understand these evolving fields. There can therefore be a university role in reaching both workforce segments. Both community colleges and universities will increasingly be offering certificates to supplement their degree programmes to scale up to meet growing needs, in part through online materials. Colleges and universities are already deeply involved in online offerings. Two leading platforms are Coursera and edX: Coursera, as of 2020, is offering some 4,500 courses from over 200 educational institutions, while edX offers some 3,000 courses from over 145 educational institutions (Bonvillian & Sarma 2021:127).

Online platforms and the courses and elements posted to them may require a university lead but will need to be tied to community colleges and industry, which will be major users. The MOOCs (massive open online courses) from universities are already increasingly focused on workforce education content – that is where the demand is. Universities are now the major developers of online workforce-related education in the US and that role could grow, making universities increasing relevant to workforce needs. Groups of MOOCs that offer career-related certificates that can be completed in a year or less, appear to be key to the future of online education.

Organising a delivery framework across institutions and skill areas could also be a university role. Take the National Science Foundation's Advanced Technology Education programme (NSF n.d.) as an example. While the programme funds go predominantly to community colleges, universities are often part of their programmes, assisting on coordination, curriculum, and online offerings. Universities could also help to assemble the consortia of employers with whom they are already working on research, that will be needed for advanced technology workforce education efforts. With ongoing technical change in the workplace, lifelong learning will increasingly also be required. Organising this into a system could also be largely a university task. Research on and testing optimal teaching models and applying lessons from learning science, particularly as online education grows and creates blended learning opportunities, could also be a university task. There are therefore critical roles that universities can fulfil in workforce education. Some universities will resist, but many are starting to enter these roles.

The great bulk of American HE is provided by state university systems, not by private colleges. These schools were initially funded as 'land grant' institutions with the revenue from federal land sales as the country was being settled. This tradition supported very practical institutions, focused on occupational needs like agriculture and mechanical arts. Therefore, asking state universities to focus on their practical roots is not a too difficult step (APLU 2017). These schools in particular are already engaged in the manufacturing institutes, and increasing their workforce role could be workable. In addition, there is another compelling force operating on universities to move in this direction. Their traditional university student base of 18- to 26-year-olds is a fading demographic in the US. Unless universities embrace new roles, including workforce education and lifelong learning, a significant number will lose their tuition base and fail (Bonvillian & Sarma 2021:136-137).

The US is facing a shortage of skilled manufacturing workers also because of demographics. The baby-boomer generation that has dominated manufacturing jobs is starting to retire at a rapid clip – there will be over two million manufacturing jobs opening in the coming decade through retirements alone (Deloitte and the Manufacturing Institute 2018:3 of 20), and these jobs are requiring increasing skills, as digital production and forms of advanced manufacturing gradually enter the workplace. There is a need for a new kind of worker – not a full engineer, but above the technician who is tied to a particular machine. This technologist position is for those who are already trained in hands-on technical skills, and who received additional education to understand the basics of production processes, systems, supply chains, and management. It can fill a gap between engineers focused on design, and factory floor technicians trained for their machines, to be flexible – both hands-on and systems-oriented, able to organise and run new information-based production systems (Liu 2020).

To these overall 'why' skills can be added the new advanced manufacturing 'how' skills such as robotics and 3D-printing for digital production. It could be a cadre educated to introduce advanced manufacturing. While European apprenticeship systems can train these 'cell leaders' to run factory operations, the US lacks an apprenticeship system (Bonvillian & Sarma 2021:177-206).

However, the colleges and universities, working with employers and community colleges, could create this new applied technologist category, filling a skills gap in production operations. Additionally, some universities are already starting to train for these new skill sets (cf. for example, technologist programmes at Wichita State University, Engineering Technology B.S. degree [WSU n.d.] and Lorrain County Community College [LCCC n.d.]). These new high-skilled, flexible manufacturing technologists will be needed to implement advanced manufacturing.

An Emerging University Role

US manufacturing has been in trouble, facing a series of problems: Low productivity rates, low investment rates in capital plant and equipment, a thinned-out manufacturing ecosystem, production scale-up difficulties, a gap in its R&D support for production technologies, a failure to regard manufacturing as part of the innovation system, and a systemic social disruption from manufacturing's decline. Advanced manufacturing is poised as a possible answer to these challenges. Its emphasis on innovation and technical advance could help to restore efficiency and higher productivity, enabling US manufacturers to better compete with lower-cost Asian producers. To that end, the US has embarked on supporting 16 new AMIs to bring its innovation system onto the manufacturing challenges for more 'manufacturing-led' innovations. These institutes combine companies, universities, and government with a focus on manufacturing technology development and supporting workforce education.

What could the university role be in these developments? Universities were involved in designing this new approach, and are actively involved in the new manufacturing institutes, both in their administration and their technology development research. In addition, American universities could play a growing role in workforce education, including manufacturing. This role could include, as detailed above, organising the delivery frameworks for workforce education, supporting online courses, platforms, and technologies, the delivery of higher end technical content, supporting lifelong learning systems, and researching learning science to improve content delivery.

What is the relevance of this recent US experience to other nations, including less developed nations? The manufacturing institute model is a potentially replicable one. The task in getting to advanced manufacturing is not developing new science for breakthrough technologies relevant to manufacturing. It is much more about taking existing and emerging technologies that are now accessible – in such areas as robotics, digital production and 3D-printing – and translating them into production systems. It is not so much a science task, it is largely an implementation task. That means that other nations that want to be competitive in manufacturing could experiment with the manufacturing institute model that has evolved in the US, with universities playing a key role. As discussed, this model brings together key actors – industry, universities, and government, both national and regional – and has them combine forces on adapting new technologies to production to improve its efficiency and lower costs. In addition, advanced manufacturing will only be adopted, as noted, if workforces are ready to implement it. Universities, again working with the same mix of actors, including other educational institutions, can join forces to enable new workforce education systems. In summary, while the US is a developed nation with a strong R&D system, its manufacturing institutes and supporting workforce efforts are instead focused on applying and implementing new technologies that are already largely available. This means those models are available to others to modify and pursue.

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