MassBridge:

Advanced Manufacturing Workforce Education Program

Benchmarking Study Phase One Report

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Massachusetts Institute of Technology
Office of Open Learning

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Table of Contents

I. Executive Summary

American manufacturing has been a troubled sector in recent decades. Between 2000-2010, the manufacturing sector lost close to 6 million jobs and closed 64,000 plants. Between 2010 and 2020, the productivity of U.S. manufacturers declined both in absolute terms and compared to key foreign competitors. The massive U.S. trade deficit in goods rose in 2018 to $891 billion, including more than $120 billion in advanced technology goods.

How will U.S. manufacturing compete with lower-wage, lower-cost competitors? Advanced manufacturing, with its potential gains in efficiency and productivity, offers a solution. Although the U.S. formed 16 advanced manufacturing institutes to help bring on new manufacturing technologies, a purely technology-focused approach will not be enough. The institutes are working to develop technologies in areas such as digital production, robotics, additive manufacturing, flexible electronics, photonics, sensor and systems, and biofabrication. However, our workforce education system is not ready to provide the training we need in these new technologies.

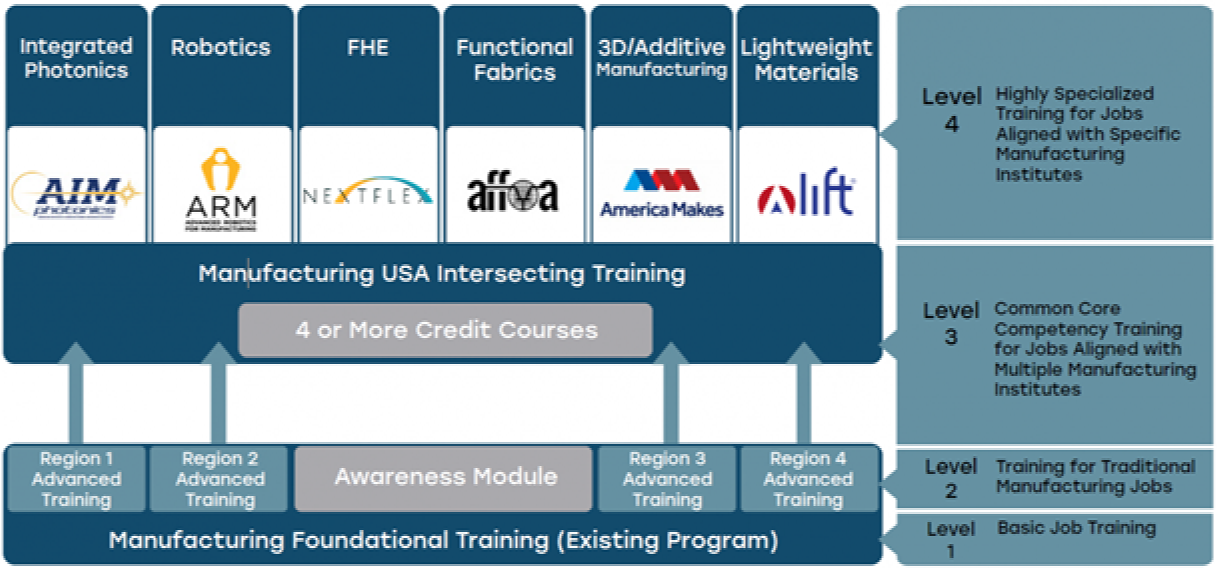
Concerned about the strength of the U.S. industrial base, the Department of Defense funded the MassBridge project. MassBridge will plan and develop advanced manufacturing programs for community colleges and vocational-technical high schools in Massachusetts. The DoD hopes that MassBridge, once successful, can also be a model for efforts in other states.

Benchmarking Approach

The MassBridge project aims to find and train the core skills that are common to advanced manufacturing technician roles but exceed the skills taught in traditional manufacturing programs. For example, photonics, flexible electronics, and additive manufacturing technicians each need specialized skills for working with their specific technologies. However, in these emerging fields, technicians may also need to take a more systems-level view than traditional manufacturing technicians to be able to troubleshoot equipment or optimize production lines or to work more closely with engineers.

In the figure below, if traditional technician programs teach level 2 skills, and the most specialized skills are level 4, then MassBridge aims to identify and train level 3 -- the common skills that can help workers be more ready for careers in any specialized manufacturing technology, with additional training in that technology. In other words, we seek to build the bridge that connects current manufacturing training programs to the advanced manufacturing future being investigated by the Manufacturing USA Institutes.

Here, some quick definitions of categories within the broader concept of workforce "credentials" are in order.[1] A "certification" is a time-limited, revocable and renewable credential awarded by an authoritative body for the knowledge, skills and abilities to perform specific tasks for an occupation. A "certificate" recognizes completion of training and mastery of learning outcomes measured by an exam or other assessment. Community colleges, universities, training providers and industry or professional associations can all offer these. An "industry-recognized certificate" is developed in consultation with industry professionals. A "community college certificate" is from a community college. A "degree" is issued by a higher education institution. A "license" is issued by a state or federal regulatory agency for an occupation. In this study, we looked particularly at industry-recognized certifications and community college certificates and degrees.



Source: Massachusetts Technology Collaborative

The benchmarking team took a two-pronged approach to develop insights and recommendations for this preliminary report. In one track, we interviewed academic and industry leaders who engage directly with workforce learning for manufacturing. This included community colleges, manufacturers, credentialing organizations, and providers of advanced manufacturing technologies. In the second track, we compiled information on the contents of 33 associate degrees, drawn largely from community colleges recommended to us for their strong manufacturing programs, and 21 industry-leading certification programs and competency models. We tagged the programs for the skills each provided and then conducted extensive analysis to identify the core skills for programs aimed at different levels of manufacturing technician specificity and sophistication.

The report is organized into five main sections, including challenges facing MassBridge, models for content delivery, recommended curriculum content, developing and launching the curriculum, and recommendations for the MassBridge program.

Challenges to MassBridge Advanced Manufacturing Training

The advanced manufacturing education system is a complex collaboration among numerous independent actors. When they are aligned, the system can work well. However, the actors' independence often leads to misalignment of incentives, programs, and outcomes. So MassBridge will need to overcome a series of barriers, and these barriers need to be considered as the program is designed. A number of the barriers that need to be considered are listed below and described in detail in the report:

1. Limited demand for advanced education from employers, particularly SMEs that have not yet adopted advanced manufacturing technologies.
2. Differing definitions of advanced manufacturing and what should be included in the program.
3. The state's independent system of community colleges makes developing a common program complex.
4. To develop strong advanced manufacturing programs and keep them updated, the linkages between employers and schools must be strengthened.
5. Degrees and certificates should prepare students for (or even embed) industry-recognized credentials, but these must be carefully selected.
6. Adapting existing programs to include extensive new material is difficult because faculty become tied to what they already teach and there is limited space in existing curricula.
7. More programs are needed to reach incumbent workers through their employers because these workers need upskilling.
8. Strong coordination will be needed with MassHire and MassMEP to reach incumbent workers and small manufacturers – they don't compete with college education missions but offer wrap-around services needed for the manufacturing ecosystem.
9. Current programs do not generate enough workers to meet anticipated needs, so scaling elements will be needed.
10. Student attrition is always a challenge; efforts are required to keep students engaged for the full programs, whether they are short-term credentials or degrees where quality jobs are the best outcome measure.
11. The program, particularly certificate programs, will need to be structured to qualify for Pell Grant student aid.
12. Advanced manufacturing equipment will need to be available to schools, whether through industry philanthropy, partnerships, consignment or state programs.
13. The curriculum will need to evolve as advanced manufacturing technologies continue to develop, and must reflect business speeds of weeks and months not semesters and years.
14. "Train the trainer" efforts will be required to help faculty become familiar with advanced manufacturing technologies, and these will need to become frequent and include mandatory externships with advanced equipment.

All of these potential barriers will need to be anticipated and planned for as the MassBridge program is developed and launched.

Models for Content Delivery

Employers in the U.S. do most workforce training, yet many manufacturing firms, particularly SMEs, will not be able to train new advanced manufacturing skills effectively. Currently, community colleges and vocational-technical high schools already assist many manufacturers in training basic manufacturing skills, while employers take responsibility for training for job-specific skills geared to their production lines. MassBridge will add another layer by providing content and education for core advanced manufacturing skills. This section describes a series of exemplary models from outside Massachusetts that could help guide MassBridge.

Currently, there are several ways that an advanced manufacturing curriculum is being developed and utilized. These include: (a) employer-led regional collaborations with area manufacturers; (b) industry-led programs by manufacturers of advanced technologies, such as in automation, robotics, process controls, and robotic welding; (c) advanced manufacturing institute programs to develop curricula and competencies in their technologies; (d) community college-led programs in collaboration with regional employers; and (e) state-led programs to develop advanced manufacturing curricula and education programs. MassBridge will utilize a combination of approaches (d) and (e), informed by the other approaches.

A series of best practices emerged from this research on models outside Massachusetts:

1. *Break down the work / learn barrier.* In all of the programs we studied, employers and educational institutions collaborate closely on content development and content delivery. Strong programs offer a work component, which can range from internships to formal apprenticeships, along with academic instruction.

2. *Employers should collaborate with each other.* Stand-alone programs where individual firms provide their own training are inherently inefficient; it is better if groups of firms share the costs and risks of workforce education. Better still is where primes and their regional SME suppliers can band together since efficient advanced manufacturing requires adoption across supply chains. Working as employer consortia can generate additional synergies when collaborating with educational institutions and state education and labor programs. Education institutions can help manage the infrastructure for these consortia, shouldering much of the administrative burden.

3. *Reach new entrant, underemployed, and incumbent workers.* Educational institutions need to adapt their program mix to reach all of these participants. If an institution – a community college or employer consortia – can reach all three groups, they become reinforcing. A program for incumbent workers requires close contact with employers, which helps keep programs for all students current with industry needs. Community college or employer programs can also reach high school students, helping to break down the work / learn barrier and link high school students to college opportunities.

4. *Embrace certificates and shorter-term programs.* In contrast to offering only full degrees earned in a fixed period of time, educational institutions should be encouraged to provide shorter-term certificates, based on acquired competencies, that can accumulate to degrees. Certificate programs can help workforce education to fit students with limited time availability and employers with particular skill requirements. Degrees that take two years or more will still be needed but can be based on a series of related, stackable credentials. This, in turn, can enable short programs that help workers get to required skills and employment earlier, plus there is a pathway toward additional skills or a degree, as desired.

5. *Embed an industry-recognized credential into education institutions' certificates.* Academic credentials are not enough. Many employers increasingly want the assurance of skill knowledge that an industry-approved and accepted credential provides. It creates an additional and parallel pathway to help students toward employment. It also ensures that academic programs are relevant to actual industry needs.

6. *Ensure access to advanced manufacturing equipment*. Employers want students who have actual experience with the latest production technologies. Because of the cost of equipment, there is a significant challenge in getting students hands-on learning, particularly for advanced equipment. One approach is for a state to create regional technology centers shared by consortia of community colleges, high schools, and employers. In addition to providing efficient student access to equipment, providing companies access can help them test and experiment with new equipment, evaluating how it can improve their production process, and assist in training for their workers.

7. *Apply new education approaches that can scale.* Offerings with new content can be blended, combining face-to-face with online education, which can help expand their reach to much higher numbers of students. Hands-on learning remains critical, but actual equipment can be supplemented with advanced technologies, including computer gaming-based courses and Virtual Reality and Augmented Reality technologies.

8. *Create programs that are eligible for Pell Grant funding.* The federal Pell Grant program for student aid was set up to promote college degrees, not workforce education, but if workforce credentials are stackable toward degrees, some schools have found ways to make these programs eligible for Pell Grant support. Without a sustainable means for funding this education, it will not be enduring, so connecting students to Pell Grants is a critical step.

9. *Create cross-state industry and community college coordination mechanisms.* A state-wide organization for manufacturers, as well as working consortia of the state's independent community colleges, that work together to implement manufacturing workforce education programs, is needed. This ongoing industry and school collaboration is key to developing new programs and keeping them current.

Identifying Advanced Manufacturing Curriculum Content

To identify an initial list of contents for the MassBridge curriculum, we synthesized data on existing programs around the United States. We built a database containing two types of manufacturing programs: associate degrees and certifications / competency models (see Appendix A of the report for the included programs). The rationale for including these two types of programs was simple: we assumed that the content of certifications and competency models represented the specific skills sought after by the manufacturing industry, while the content of associate degrees represented the educational system's approach to meeting those needs for the local business environment. One goal of this benchmarking effort was to identify areas where the two perspectives might not be so well aligned, indicating a gap in one side or the other.

We classified the programs into levels based on the "advancedness" of the manufacturing career that they prepare for, based on the program name and stated focus. These three levels reflect the three main employment opportunities that emerged from data analysis and interviews:

- **Level 10: Manufacturing technician:** In this level, students would learn the basic fundamentals of manufacturing, after which they might enter the workforce as manufacturing technicians.
- **Level 20: Advanced manufacturing technician:** this level adds more sophisticated manufacturing technologies and methods, as well as providing system- and process-level understanding to assist in maintenance and troubleshooting.
- **Level 30: Specialized/connected advanced manufacturing technician:** This level includes extant programs covering technologies and techniques associated with the six Manufacturing Institutes included in MassBridge. It also includes programs that have an explicit focus on connected manufacturing such as Industry 4.0.

In addition to identifying these levels of current content, the report identified a potential need for a "technologist" who could be trained in elements of advanced manufacturing areas now starting to enter the workplace, such as digital production, robotics and additive manufacturing, but also master core skills in such areas as systems operation and thinking, production processes, troubleshooting and critical thinking. While such technologists would not have the full mastery that specialists in particular areas of advanced manufacturing have (these are the level 4 skills in the figure above), they would be able to work above the technician level tied to particular pieces of equipment, and work across equipment types and within a digital thread environment to reach the level 3 area in the figure above.

To identify core topics for the MassBridge curriculum, we coded each element of each degree program or certification using a standardized list of 145 topic tags constructed for this project. We then used this information to identify "core" lists of topics that characterize the content of programs at each "advancedness" level of manufacturing, using the method described in Appendix B of the report.

The following table compares the core topics across all three levels of curriculum. In general, there is extensive overlap since more advanced levels still build upon many of the topics in less advanced ones. The topics that are part of the core at all three levels tend to be industry-specific subjects that are either very comprehensive (e.g., safety, quality, manufacturing processes) or very basic (e.g., blueprint reading, basic measurement). Other industry-specific skills that are crucial components no matter the level include electronics, systems control, manual machining, and machine tools. The list also includes a number of human skills and general education skills such as lower-level mathematics, communication, critical thinking, reading comprehension, and professional skills.

	Core Topic		
	Level 10	Level 20	Level 30
Basic Measurement	Yes	Yes	Yes
Communication	Yes	Yes	Yes
Critical Thinking	Yes	Yes	Yes
Electronics	Yes	Yes	Yes
Lower-Level Mathematics	Yes	Yes	Yes
Machine Tools	Yes	Yes	Yes
Manual Machining	Yes	Yes	Yes
Manufacturing Processes	Yes	Yes	Yes
Problem-Solving	Yes	Yes	Yes
Professional Skills	Yes	Yes	Yes
Quality	Yes	Yes	Yes
Reading Comprehension	Yes	Yes	Yes
Safety	Yes	Yes	Yes
Systems Control	Yes	Yes	Yes
Technical Blueprints & Drawings	Yes	Yes	Yes
CAD/CAM	Yes	Yes	No
CNC Machining	Yes	Yes	No
GD&T	Yes	Yes	No
Manufacturing Systems	Yes	Yes	No
Research	Yes	Yes	No
Manufacturing Materials	Yes	No	Yes
Ethics	Yes	No	No
Statistical Process/Quality Control	Yes	No	No
Instrumentation & Sensors	No	Yes	Yes
Introductory Physics	No	Yes	Yes
Maintenance	No	Yes	Yes
PLCs	No	Yes	Yes
Robotics	No	Yes	Yes
Troubleshooting	No	Yes	Yes
Mechanical Elements & Power	No	Yes	No
Mechatronics Systems	No	Yes	No
Quality Control	No	Yes	No
Automated Systems	No	No	Yes
Basic Computer Skills	No	No	Yes
Basic Mathematics	No	No	Yes
Data Management	No	No	Yes
Hand Tools	No	No	Yes
Hydraulics	No	No	Yes
Pneumatics	No	No	Yes
Probability & Statistics	No	No	Yes
Process Control	No	No	Yes
Scientific Communication	No	No	Yes
Simulation	No	No	Yes

However, the table also makes it clear how each successive level adds unique topics that are not the focus of traditional Level 10 programs. In Level 20 programs, a focus on more advanced technical subjects starts to emerge, such as knowledge of instrumentation techniques and PLCs. In fact, level 20 programs appear to lay the groundwork for the connected manufacturing that is the focus of a subset of Level 30 programs, as evidenced by the prevalence of both mechatronics systems and robotics. Core technical skills such as troubleshooting and maintenance also appear here for the first time. Finally, Level 30 programs suggest a more integrated and digitized approach to manufacturing, as evidenced by the importance of automated systems, as well as a number of digital skills such as basic computer skills, data management, and simulation. This level's focus on probability and statistics suggests that the ability to manipulate and interpret data is an important element of these programs, potentially in the context of production planning and decision-making roles.

There are a few apparent anomalies in the data, such as the fact that the manufacturing materials topic appears in levels 10 and 30 but not level 20. This is a function of the academic programs and certifications in our database as well as our analysis methodology. For this and other reasons, a purely unsupervised approach such as we used nearly always needs manual intervention to apply knowledge that is not embedded in the data itself. Therefore, as a next step, we plan to work with the MassBridge curriculum team, as well as industry and academic experts, to validate and enhance our initial analysis.

Based on our analysis, after reviewing the findings with industry and academic experts, we recommend that the MassBridge curriculum include topics from the level 20 and 30 columns of the table above. Each topic is mapped back to existing programs that teach the topic, opening the possibility of re-using or adapting existing content instead of building it from scratch. Working with the MassBridge curriculum development team, we can converge on the specific topics and content elements for the MassBridge program.

Developing and Launching the Curriculum

Developing a shared or standardized curriculum is difficult. Developing it in a domain as complex as advanced manufacturing adds even more difficulty. Manufacturing-related AA degrees in most schools have little room to add several new courses and competencies. Finding faculty willing to undertake the change or teach the new skills will also be challenging. Moreover, finding employers who want to hire the graduates or sponsor work-learning collaborations adds difficulty.

Our interviews and other analyses identified four approaches that MassBridge could take to develop its curriculum. These include:

- Building or curating plug-in modules that schools can add to their existing programs,
- Creating a third-year advanced manufacturing technologist program
- Recreating the two-year technician program as an advanced manufacturing program from the ground up
- Focusing on years two and three of a three-year program, where vocational-technical high schools could provide year one and community colleges years two and three.

Recommendations of the Preliminary Benchmarking Study

Detailed recommendations in the final section of the report are briefly summarized here:

Program content

1. *Emphasize the why and how not just the what.* Manufacturing "technologists" require a mindset change from direction-follower to systems thinker. They need to understand manufacturing as a system, including production processes, supply chains, and management.

2. *Build a core for each level plus specialized options.* We need core curriculum components at the traditional, advanced, and connected levels of sophistication. All need to be more "applied learning" oriented. The resulting programs should maintain a multi-level modular approach so that educators can easily understand how to tailor their existing programs for higher tiers of advanced manufacturing.

3. *Include professional and other "human" skills.* In addition to technical skills, employers value non-technical skills that are not typically taught in school. Advanced manufacturing requires skills such as critical thinking, problem-solving, curiosity, leadership, and adaptability.

4. *Break down the work / learn barrier.* In all of the programs described in this report, institutions collaborate closely on both content development and content delivery. Strong programs go beyond that to offer work components that range from internships to formal apprenticeships. We need earlier career/education guided pathways, not adding more time but replacing non-essential material with real-world, project-based learning modules that emphasize competencies not traditional academic approaches.

5. *Tie to industry credentials and badges.* Academic credentials alone can be a weak signal of skill, particularly if employers are not aware of a school's programs. Many employers increasingly want the assurance that an industry-approved and accepted credential provides.

6. *Ensure that programs are eligible for financial aid.* Short non-degree programs, and certificate programs that occur after graduation from a standard degree program, need to be structured to be eligible for federal student aid such as Pell Grants.

Curriculum design process

7. *Consider multiple development approaches.* We suggested four approaches to developing the MassBridge curriculum, as discussed above. These options are not mutually exclusive and, in fact, can be complementary. Different institutions will be amenable to different approaches.

8. *Shift the mindset from creation to curation.* Our research uncovered numerous exemplary programs ranging from traditional manufacturing to advanced technologies. The programs, and the training systems they are embedded in, provide numerous examples that MassBridge can build upon rather than recreating. Where a new curriculum is required, the advanced manufacturing institutes can be drawn on.

9. *Embed appropriate evaluation mechanisms.* MassBridge should plan for broader program-level measures such as employment outcomes or career growth, in addition to detailed course-level measures.

10. *Use modular approaches to deliver customized programs with standard quality*. MassBridge can develop standard modules and model curricula in a number of advanced manufacturing technologies from which schools can choose. This modular approach can also enable the four curricular approaches suggested above. Schools can even build upon or rebuild modules to adjust them for specific technologies or software tools. In this way, MassBridge can move from being a single set of courses to a library of modules that meet the needs of different schools and employers.

11. *Build collaboration between the six pilot schools – and with employers.* MassBridge could build a collaboration program and curriculum clearinghouse for all of the state's community colleges, through which school representatives meet periodically to share best practices and new manufacturing curricula. To ensure that programs meet employers' needs, MassBridge also needs an ongoing mechanism with employers to coordinate the requirements they present to educational institutions.

12. *Ensure that the curriculum design works for underemployed and incumbent manufacturing workers in addition to new students.* The advanced manufacturing skill gap can only be filled by a combination of training new students and upskilling existing workers. In building curriculum, ensure that the design enables incumbent workers to gain skills they need quickly and easily, while accumulating to broader degrees over time. Modular programs, stackable credentials, credit for existing knowledge and experience, digital / hybrid programs, and collaboration with employers to train their workers can all be helpful in this regard.

Scalability

13. *Better availability and use of equipment.* Community colleges have challenges in providing manufacturing students enough hands-on time with up-to-date, advanced machinery. Shared equipment centers and M2I2 capital equipment programs may help.

14. *Use technology to maximize the value of limited hands-on time*. Software tools and online platforms can be an effective way to scale the productivity of capacity-limited hands-on labs and programs.

15. *Scale up the upskilling.* In addition to demand-side programs to increase participant interest in manufacturing jobs, manufacturing educational programs will need to grow in size and content breadth to meet workforce needs for the new advanced manufacturing skills. As importantly, incumbent manufacturing workers will need upskilling to keep up with new technologies. Programs must scale to meet the need.

16. *Energize a community for content development and delivery.* Consider MassBridge as a library of materials that can grow over time. Enable local schools to customize MassBridge modules for their specific contexts. Foster programs to encourage sharing curricular innovations, not only across Massachusetts but nationwide. Conduct conferences and contests through which educators can share their ideas and receive broad recognition for their contributions. Energize a community around the goals of MassBridge.

Conclusion

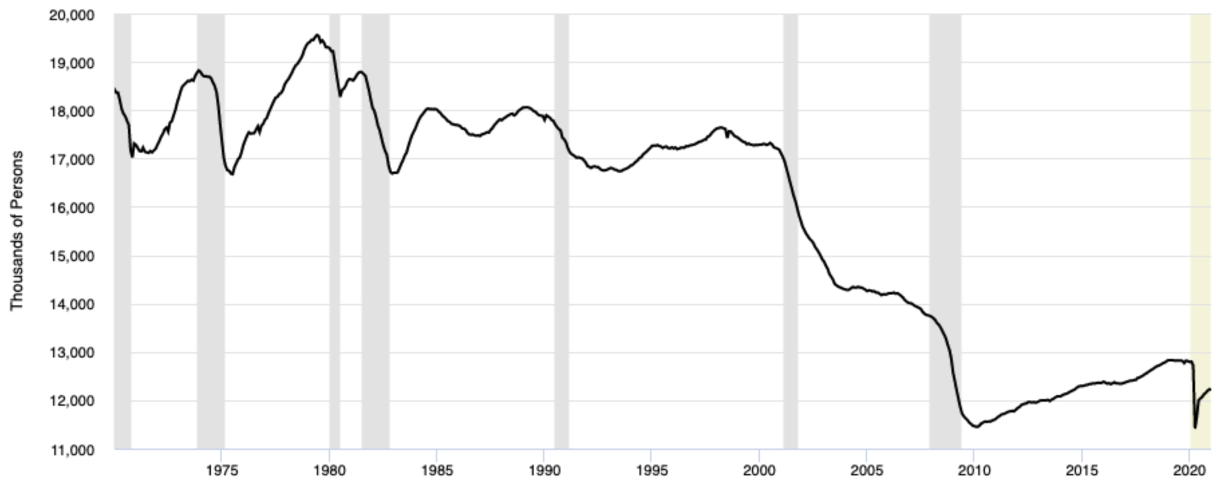
It is important to understand, up front, that the success of a new workforce training program for advanced manufacturing skills will only succeed if the state's manufacturing firms are adopting new advanced manufacturing technologies. Firms, particularly SMEs, are reluctant to train skills for new equipment they don't yet have. Therefore, workforce training efforts must proceed in parallel with advanced technology implementation efforts, including Massachusetts' unique M2I2 program to assist firms and research institutions in acquiring advanced manufacturing capital equipment.

Overall, development and dissemination of advanced manufacturing content requires use of existing curricula where available for closer-in manufacturing technologies and new curricula for further-out technologies. For both, the manufacturing innovation institutes may be able to play a constructive role in support of the MassBridge project. DoD ManTech's pending online platform to collect and disseminate advanced manufacturing online content could be a useful resource. The MassBridge advanced manufacturing education content could be implemented through the improved delivery systems discussed above, with employer or educational-led collaborations helping to develop and broadcast the new content, and adopting a series of new best practices to do so.

II. Industry Backdrop: Declining Manufacturing Employment and Capability

American manufacturing has been a troubled sector in recent decades. A clear signal of U.S. manufacturing problems has been stagnating productivity. Between 2010 and 2020 the productivity of U.S. manufacturers declined both in absolute terms and compared to key foreign competitors. While the U.S. manufacturing has experienced declining rates of productivity since 2010, European Union, German and Japanese productivity has been rising.[2] The loss of 5.8 million manufacturing jobs – nearly one-third of the total – between 2000 and 2010 was a signal not of improving productivity but of output decline.[3] U.S. manufacturing was passed in output by China in 2011[4] and it took a dozen years for its output to return to its 2007 levels in 2019.[5] The U.S. ran a massive trade deficit in goods rising to $891 billion in 2018,[6] including a 2018 deficit of over $120 billion in advanced technology goods.[7] The job loss data was a signal of a hallowing sector, with 64,000 plants closing from 2000-2013.[8]

Figure 1: U.S. Manufacturing Employment, 1970-2021.



Source: U.S. Bureau of Labor Statistics, St. Louis Fed.

Overall U.S. manufacturing productivity is at historically low levels,[9] and behind this is a low level of capital investment in plant and equipment.[10] This is exacerbated by a growing productivity gap between large and small manufacturers, where productivity rates have been stagnating.[11] This productivity problem, particularly acute with these small and mid-sized enterprises (SMEs), shows there is an innovation system gap. There are some 250,000 of these manufacturing SMEs nationwide that employ less than 500 workers and they produce some 46% of U.S. manufacturing output.[12] So this is a serious drag on the U.S. production system. The U.S. has not been bringing on the new manufacturing technologies at a fast enough pace to keep up with its competitors. This spells further decline unless it is reversed.

1. **National investments in improving technology and skills**

In an attempt to restore its manufacturing sector and its productivity, between 2012 and 2017 the U.S. created the Manufacturing USA network of Innovation Institutes.[13] Three agencies, the Department of Defense (led by its ManTech program), the Department of Energy (led by EERE's Advanced Manufacturing Office), and the Department of Commerce (led by NIST's Advanced Manufacturing Office) have established 16 Institutes, each focusing on a particular advanced manufacturing technology area and cost-shared with industry and state economic development agencies. Institutes are loosely modeled on the German Fraunhofer Institutes,[14] bringing together university research institutions and manufacturing firms. The total federal support for the manufacturing innovation institutes has been over time approximately $1 billion.

However, the U.S. investment in advanced manufacturing is modest compared to its competitors. China and Germany, among other nations, have invested in similar industrial policy efforts – Germany's Fraunhofer network conducts applied manufacturing research with an annual budget of approximately $2.8 Billion derived from the private sector and government sources.[15] The Made in China 2025 manufacturing initiative, which includes a manufacturing institute-like program, has received hundreds of billions of dollars in public funding, according to some estimates.[16]

There are two generally recognized ways to improve productivity: through the new capital plant and equipment investment and through a more efficient workforce. The manufacturing institutes were envisioned, in the original 2012 industry-university Presidential task force report recommending their creation, as supporting both tasks, and both were contemplated in the original Congressional legislation for the institutes.[17] However, like American manufacturers, they have tended to adopt a strong tilt toward the capital side, emphasizing new technology development over workforce education.[18] In contrast, German manufacturers believe that a production equipment efficiency lead cannot be not long-lasting because the new equipment will spread quickly among world competitors, while a well-trained workforce offers a more enduring competitive advantage – it takes much longer to establish a strong workforce education system than to buy the latest production equipment. German producers apply both strategies, in contrast to U.S. producers, which have generally not focused on a workforce strategy. There has been a growing emphasis in the federal agencies on manufacturing workforce programs, particularly DoD's ManTech which has been concerned about erosion in the defense manufacturing base.

2. The Massachusetts manufacturing sector

Although Massachusetts manufacturers suffered in this U.S. manufacturing decline, the state still has a solid manufacturing sector, with over 6,200 manufacturing companies employing nearly 245,000 workers, who earn an average wage of over $100,000 a year.[19] The state's manufacturing output was $53.3 billion in 2018. Prominent within this sector, and of interest to DoD's ManTech program, is a strong defense industrial base that includes 2,200 companies that contract for DoD, including for some of its most advanced technology programs.[20] When multiplier and regional supply chain effects are factored in, the defense sector's economic impact in the state is over $20 billion in output and helps support 88,000 workers on top of 36,000 direct jobs.[21] The state's top defense primes include some of the nation's most prominent defense firms and research centers.

Since 2010, American manufacturing sector employment has been stabilizing, with over one million manufacturing jobs added between 2010 and 2021. Because of the aging demographics of the manufacturing workforce more than two million jobs are expected to open up in the coming decade.[22] But these levels are contingent on manufacturing productivity improvements. If advanced manufacturing can be introduced and the workforce is ready to implement it, the decline of production can be reversed and further jobs will open up.

III. MassBridge Program and Benchmarking Methodology

The MassBridge project, supported by DoD ManTech, is attacking the workforce productivity side of the equation. It is an attempt to convene state education, labor, and economic development officials, working with industry and education institutions, to collaborate on a state plan for training the state's advanced manufacturing workforce.

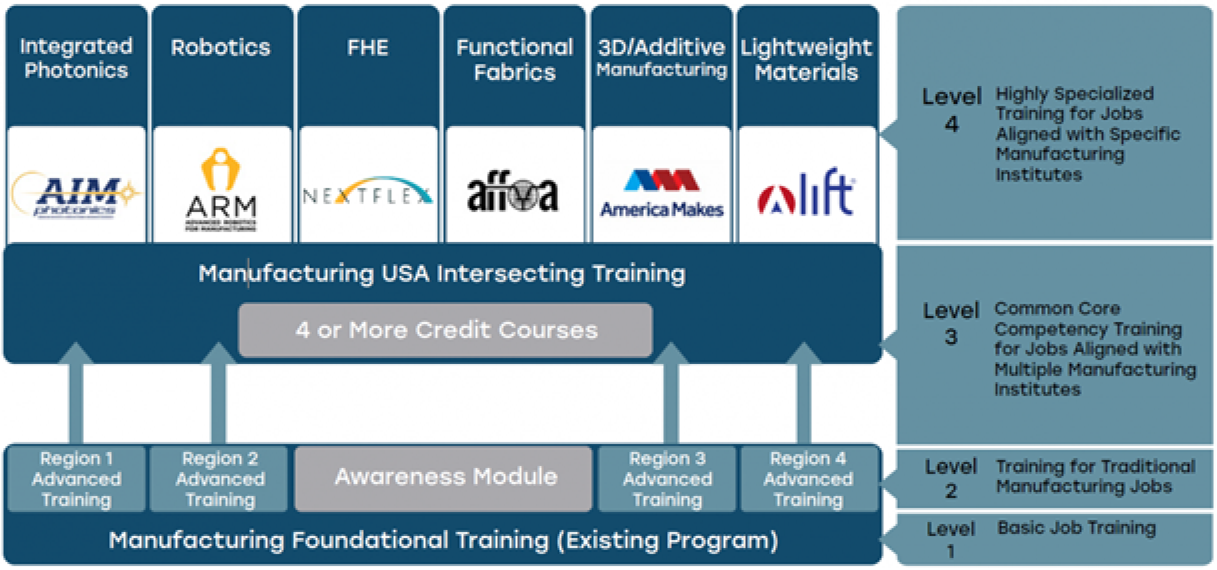
The purpose of the program is to identify the skills that technologically-advanced manufacturing firms will need to fill advanced production jobs in the coming years and to develop curricula and supporting certifications to help workers gain those skills.

In particular, the project aims to find and train the core of skills that are common to advanced manufacturing technician roles, and that exceed the skills commonly taught in traditional manufacturing programs. For example, photonics, flexible electronics, and additive manufacturing technicians each need a set of specialized skills for working with their specific technologies. However, in these emerging fields, technicians may also need to take a more systems-level view than traditional manufacturing technicians, to be able to troubleshoot equipment or optimize production lines, or to be able to work more closely with engineers.

Currently, employers looking for technicians with specialized skills often need to hire smart technicians and spend two-to-three years training them for the advanced technician role. MassBridge seek to shift some of that time and effort from individual employers to a community college curriculum, allowing workers to graduate more ready for advanced manufacturing roles, and halving the time employers must invest to bring them up to speed on the technologies

Figure 2 shows the positioning of the MassBridge project. If traditional technician programs teach level 2 skills (see Figure 2), and the most specialized skills are level 4, the MassBridge project aims to identify and train level 3 -- the common advanced manufacturing skills that can help workers be more ready for careers in any specialized technology, with additional training in that technology. In other words, we seek to build the bridge that connects current manufacturing training programs to the advanced manufacturing future being investigated by the Manufacturing USA Institutes.

Figure 2: The MassBridge Training Context: Building Level 3 Curriculum



Source: Massachusetts Technology Collaborative

An essential part of MassBridge, the benchmarking project described in this report is an attempt to identify curriculum content and delivery practices from around the nation to inform the new education model MassBridge seeks to build. This initial report will identify key challenges identified in our analysis, then provide models for content delivery and for content development. As this is a preliminary report, the models and recommendations are just a starting point for discussions. Further discussion and analysis will provide essential guidance for the development of the MassBridge advanced manufacturing education system. As the data above indicates, the challenge is an important one for the future of the Commonwealth and the nation.

1. Benchmarking methodology

The benchmarking team took a two-pronged approach to develop insights and recommendations for this preliminary report. In one track, we interviewed academic and industry leaders who engage directly with workforce learning for manufacturing. This included community colleges, manufacturers, credentialing organizations, and providers of advanced manufacturing technologies (See Table 1). The interviews provided a wealth of information on challenges and effective practices for manufacturing training systems, especially among community colleges which are the target delivery channels for the MassBridge curriculum.

Table 1: Research Interviews (see selected summaries in Appendix D)

Organization	Type
Amatrol	Credentialing
Amtek	Credentialing
Asnuntuck CC	Community College
Bristol CC	Community College
Cape Cod CC	Community College
FANUC	Industry
Festo	Credentialing
Gateway Technical College	Community College
Ivy Technical CC	Community College System
Kentucky Community and Technical College System	Community College System
Lincoln Electric	Industry
Lorain County CC	Community College
Manchester CC	Community College
MassHire	Work Placement
Monroe CC	Community College
NIMS	Credentialing
Ohio Manufacturing Association	Industry Consortium
Ohio TechNet	CC Consortium
Peerless Precision	Industry
Purdue University	University
Quinsigamond CC	Community College
RAMTEC	Industry
Rockwell Automation	Industry
Smart Automation Certification Alliance (SACA)	Credentialing
Siemens	Industry
Workcred	Credentialing

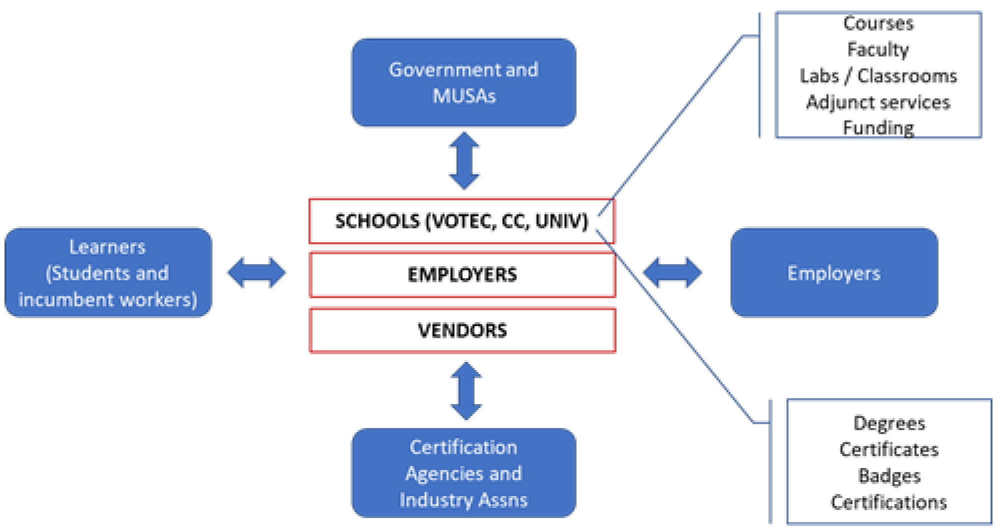
In the second track, we compiled information on the contents of 33 associate degrees (drawn largely from community colleges recommended to us with strong manufacturing programs) and 21 industry-leading certification programs and competency models and tagged them for the skills provided in each. This data provided an empirical basis to identify commonalities among curricula at different levels of technical specificity and sophistication.

The project team developed its recommendations by combining qualitative and quantitative information in an iterative process of convergence. The findings presented here should be considered a starting point for further discussion and iteration in collaboration with curriculum developers and industry representatives.

IV. Challenges in the Advanced Manufacturing Education System

The advanced manufacturing education system is a complex collaboration among numerous independent actors (Figure 3). When they are aligned, the system can work well. However, the actors' independence often leads to misalignment of incentives, programs, and outcomes. Multiple providers teach multiple courses, with different contents, to different types of students at different levels of depth and quality. Employers are unable to assess the quality of program graduates for all but the most familiar institutions, yet there is little agreement about accepting the multiple certifications available. Students, meanwhile, face real challenges in identifying, funding, and then persisting in, multi-semester programs that do not show clear value before graduation.

Figure 3: The Complex Structure of Today's Manufacturing Education System



Our interviews and literature review highlighted a number of important challenges to the development of a well-functioning advanced manufacturing education system.

1. Lack of demand from employers

Employment demand for advanced manufacturing skills reflects a chicken-and-egg dilemma, especially among Small and Medium Enterprises. There is a growing gap between large manufacturing firms and SMEs in productivity. Underscoring that gap, two recent surveys of manufacturing executives, including in Massachusetts, highlighted the reluctance of SMEs to adopt advanced manufacturing technologies.[23] These small firms typically indicated that they will not try to train for new manufacturing skills until the actual new technology arrives on their factory floors. This means that the adoption of advanced manufacturing equipment will be a prerequisite for many to undertake training and hiring for advanced manufacturing skills.

The implication is that we cannot fix workforce education without creating a greater and different demand for trained workers – and that such demand will only emerge from more technologically-advanced firms. Most of today's SMEs are satisfied with the relatively low level of skills of the new entrant workers they hire. In the surveys, many SMEs say they just want new workers to come to work on time and be satisfied with relatively low initial wages. That attitude toward advanced manufacturing skills will only change when these SMEs acquire more advanced technology. A program that focuses only on worker-training without a parallel and complementary effort to encourage employers to acquire new advanced manufacturing equipment may not create enough employer demand to work. Technology acquisition is therefore a central issue for a new advanced workforce training program.

Fortunately for MassBridge, Massachusetts is the only state we have identified that has a program for the adoption of advanced manufacturing equipment by firms as well as educational institutions. The Massachusetts Manufacturing Innovation Initiative (M2I2), which provides grants to firms and research institutions for new capital equipment to improve their technological capabilities. The grant program, which has awarded more than $50 million thus far, is designed to defray the costs and the risks of acquiring new technologies for the state's research universities and manufacturing firms. This is a potentially important tool to use in concert with new workforce development plans.

2. Differing definitions of advanced manufacturing

Our interviews uncovered differing understandings of what the concept of advanced manufacturing means, or what skills are required in advanced manufacturing workers. Some respondents focus on specific technologies such as robotics or additive manufacturing. Many describe advanced manufacturing in terms of the new generation of manufacturing including sensors, automation and connected systems. For others, advanced manufacturing is represented in the topics of their most recently updated curriculum or certification.

The challenge is further reflected in the diversity of advanced manufacturing programs already being taught across the country. The situation is one of plenty in some areas, scarcity in others, and, unfortunately, title inflation in others. This created a challenge in our curriculum content analysis. Many courses are called advanced manufacturing, but they vary in "advancedness". Meanwhile, for the most advanced technologies and skills -- especially those aligned with specific manufacturing institutes -- there are far fewer programs and certifications.

For example, there are two kinds of federally-supported manufacturing institutes. First, those developing technologies that are already being adopted in manufacturing workplaces (such as digital production, robotics, and additive manufacturing), which are "closer-in" to adoption. And second, those institutes focused on new technologies in the R&D and development stages (such as flexible electronics, photonics, biofabrication), and are "further-out" from adoption. For some advanced skills -- especially those aligned with the "further out" manufacturing institutes – the curriculum is not there yet, which limited our ability to quantitatively assess common skill requirements. While our interviews provided ways to fill many of the gaps, there is still more to be done at the further-out end of the advanced manufacturing skill spectrum.

In MassBridge, we will focus on two categories of core advanced manufacturing skills: higher-level systems thinking, and connected manufacturing (sometimes called Industry 4.0 or digital production, including robotics). Skills specific to a number of "further out" advanced manufacturing technologies are not included yet, since we have not been able to locate adequate curricula or industry certifications for them. To summarize, curricula are available for core advanced manufacturing skills and connected manufacturing, as defined above, but less so for the "furthest out" technologies.

As the "further-out" technologies enter workplaces, curricula will have to be developed on an ongoing basis, likely using connections with manufacturing institutes working in these fields. Training for specialists who will focus on specific advanced manufacturing skills also falls more into level four rather than level three of the MassBridge curriculum stack (see Figure 2 above).

3. Independence of MA community colleges

Massachusetts community colleges operate independently from one another. This allows them to focus on the needs of the local economy. However, it can make it difficult to coordinate programs across regions. It can also create a challenge for students who move to other regions or employers considering graduates from other regions. A course, or program, from another region, may be taught at a very different level of specificity. It may involve more or less problem solving or hands-on training than local schools. This creates murkiness in the labor market at a time when manufacturing is experiencing an advanced manufacturing skills gap.

Massachusetts already has coordination mechanisms to manage the investment in new programs. Under state Education Department procedures, new certificate programs and new concentrations go through an approval process at the state level.[24] The approval process, while it can be somewhat lengthy and cumbersome, can help ensure program coordination across schools Below we share other ways that MassBridge can foster coordination and innovation sharing across community colleges without mandating additional pre-emptive governance processes.

4. Inadequate linkages between employers and schools

Existing and new manufacturing programs need to be attuned to industry needs to ensure that there will be jobs for program graduates. It is a well-understood best practice for community colleges and vocational technical high schools to integrate course and program development with industry However, this should go beyond an occasional advisory board meeting and stem from a real integration in the program development, with curriculum kept current through continuing connections. The BILT Model for employer engagement with community colleges offers an integrated approach for company involvement.[50] Too often, new programs are developed without this kind of integrated effort and this disconnect affects program quality and industry acceptance. There is an additional issue in Massachusetts, as well, that affects coordination between manufacturing employers and schools: there is not a single state industry association that represents manufacturing firms. There are also manufacturing associations in some but not all state manufacturing regions, which also affects coordination.

5. Knowing what graduates know: Lack of certifications

A generally-accepted best practice for community colleges is to offer degrees and certificates that imbed an industry-accepted credential. Manufacturing does not have a single unified system for establishing industry-approved, industry-recognized, and transportable credentials for workers, Instead, there are many competing systems. The result is that many employers simply do not use them in hiring. Some credentials are industry-developed, such as by Fanuc, Rockwell Automation, Siemens and Lincoln Electric, which tend to tie in to their equipment. There are online for-profit providers such as 180 Skills, Thors, and ToolingU that tie their own credentials to their programs, and firms that combine training equipment and online education such as Amatrol. And there are independent non-profit organizations like SACA, NOCTI, AWS and NIMS, that both develop credentials and provide assessments for them. MSSC has developed a general set of advanced manufacturing skills with a certification to go with them, but these focus more on foundational information about emerging fields, not specific hands-on skills. A number of Massachusetts community colleges have relied in part on a general manufacturing skill certification system developed by MassMEP, MACWIC, although these do not embrace advanced manufacturing skills. In general, Midwestern community colleges tend to imbed industry-approved certificates in their programs, with regional employers that recognize them, while Massachusetts schools do less of this.

Few credentials have yet developed for the new further-out advanced manufacturing technologies. Recognizing that industry-recognized certifications can be key to the efficient development of advanced manufacturing education content, both for firms and educational institutions, some manufacturing innovation institutes have begun to be involved in developing such certifications in their new advanced manufacturing fields (see, for example, efforts at America Makes, ARM and BioFab). This can be a constructive step.

6. Difficulty of adapting existing programs

Community college curricula in manufacturing have grown over the years to include many important skills such as CNC machining, mechatronics, and process controls. Core academic requirements in communication, math, and other subjects add additional curriculum hours. Associate degree programs that bridge to four-year programs add further requirements. New topics often enter as additions, rather than providing a chance to rethink or recombine courses, lessons, and exercises and exercises. As a result, new curricular requirements often do not displace as much as they add, creating a feeling among faculty and administrators that there simply is not enough room to incorporate new topics into the curriculum.

In addition, educational institutions can encounter inertia in their curriculum development and change processes. Busy faculty may prefer to focus on what they know rather than learning how to incorporate new topics into their courses. They may be disconnected from current industry practice, or feel a lack of confidence in covering the new topics. Coordinating changes across faculty and internal programs can be difficult as each group argues for its way of teaching or its share of "turf." Tenure and other labor policies can embed the inertia even as new or more innovative faculty embrace the change.

To meet its goal of teaching new skills for advanced manufacturing careers, and to promote adoption beyond the pilot schools, MassBridge will need to overcome the fear of curricular overcrowding. It will also need to find ways for busy faculty and administrators to ease the transition to new curricular content, such as by helping to rethink and recombine, rather than just adding new materials.

7. More focus on incumbent workers: In addition to reaching more new entrants we also need more upskilling programs for incumbent workers

As advanced manufacturing technologies enter workplaces, upskilling of the existing workforce is required, as well as educating more new entrant workers. Community colleges frequently reach students now in the workforce – perhaps half of current programs involve incumbent workers – but more could take advantage of more direct and more intensive relationships with manufacturing firms, particularly groups of firms, to take on incumbent worker training. And this will mean more programs directly at employer sites. Solving the workforce challenge for advanced manufacturing will often lie in upskilling current workers for the new manufacturing skills, so there will be a greater need for schools to develop direct training programs with and at manufacturers. This is also an opportunity because training incumbent workers on site is a useful forcing mechanism that requires schools to engage more closely with regional manufacturing firms and their needs – it further ties the two together in ways that benefit both.

8. Coordinating advanced manufacturing training with MassHire and MassMEP

MassMEP has ongoing program outreach to many of the state's manufacturing SMEs, and workforce education is an issue it has advised on. MassHire's workforce development boards distribute funding to providers for large-scale workforce education for displaced and underemployed workers, often coordinated through community colleges and vocational technical high schools. Both organizations are part of MassBridge. The MEP and workforce board programs don't compete with the community college mission of education, but they can offer "wrap-around" services necessary for the success of a total workforce ecosystem, by connecting to SMEs with workforce needs and to potential worker communities. It is important that these organizations are involved in and not disconnected from advanced manufacturing curriculum development, so they can play a role in implementing it.

9. Filling the pipeline of candidates: current programs won't generate enough workers

Current state programs for manufacturing education, while important, don't train at the volume to meet future projected manufacturing needs, which are projected to increase significantly because of retirements due to an aging workforce. And there is already a demand for workers in the state's manufacturing sector. So improving existing education offerings on advanced manufacturing will not be enough; programs will need to expand the skilled talent base, as well. An outreach program, which MassBridge has begun, to encourage interest in manufacturing employment by students will be needed because, given the history of manufacturing job decline, students have not been interested despite the job and pay opportunities. If this interest can be generated, it will be difficult to scale current programs. So scaling elements, including online education features, will be needed. And the issue of employers not yet demanding advanced manufacturing skills remains, as noted above. In summary, MassBridge needs to consider not only how to build the curriculum, but also how to make it scalable to meet the workforce need. This will require focus from both the demand side – students, parents, and employers, and from the operational side – equipment, instructors, facilities, and online elements.

10. Student Attrition: keeping students engaged for a full degree

Overall community college completion rates for first-time full-time students in Massachusetts are lower than desired, in the 20% range.[25] While manufacturing programs tend to have higher completion rates, many schools could do more to help students complete their learning. Community college students tend to be older than typical four-year college students – age 28.[26] They also tend to be more likely to be working in addition to school or to have family responsibilities. Schools are already doing many things to help, such as offering courses on weekends or after hours, and building hybrids of digital and in-person classrooms to allow flexible learning and schedules. However, more can be done to help students see accomplishment, and potentially earn extra value, along the way. Shorter-term, stackable credentials rather than full degrees, that are directly related to advanced manufacturing credentials can be the objective, with quality job outcomes not program time as the measure of success. Examples below highlight ways that some institutions are using apprenticeships, work opportunities, and micro-credentials to make this happen.

11. Funding: need to match Pell Grants and other mechanisms

It's an unfortunate reality that most CC students would not be able to attend school without financial aid. In particular, federal Pell Grants, which provide student aid for college costs for students with financial needs, have been an essential enabler for learning for millions of students. However, unless enrolled in a college program – two-or four-year degrees - students are not eligible for Pell Grants. While employers sometimes pay the bill for their employees, this mechanism will not work for students who wish to enter the field.

The need to tie to Pell Grant mandates will complicate the process of creating innovative non-degree methods to train advanced manufacturing skills. For example, short certificate programs may be valuable to help workers take the next step in their careers, but depending on how structured, may be ineligible for Pell Grants. In addition, training that spans the gap between two and four-year programs, such as a semester- or year-long program that builds atop traditional two-year manufacturing programs, may require an articulation agreement linking the program with a four-year institution. In an era when lifelong learning will become a paramount concern, the Education Department will need to rethink the linkage between Pell Grants and workforce education, but meanwhile, MassBridge will need to consider student funding programs when considering its curriculum options.

12. Equipment availability

Advanced manufacturing training will require hands-on work with new equipment that can be large, complex, and expensive. Community colleges already experience challenges in providing manufacturing students with enough hands-on time with up-to-date machinery. Currently, available equipment may be non-standard, sometimes outdated, or under-maintained. In other cases, it can be under-utilized because it is dedicated to specific programs and not shared. Or it may be located in the site that was able to procure it, but distant from other programs that could share it.

This situation is often a symptom of ineffective and disconnected grant funding approaches. Community college leaders have described to us their occasional scramble to get grants for updated equipment, then the grant expires and they have to find resources to maintain and repair it, then a new grant arrives and they buy different equipment.

MassBridge will need to address the equipment challenge inherent in building and scaling advanced manufacturing training programs. Simulators such as Amatrol's widely-used Skill Boss, or newer AR/VR approaches can help. However, the situation will require careful consideration to ensure that MassBridge builds its curriculum on accepted technologies and that institutions hoping to adopt the MassBridge curriculum will be able to access the necessary hardware and software tools.

13. Evolving and updating the curriculum

Technology changes quickly, but organizations – and industries – change much more slowly.[27] In the three-year time span of the MassBridge program, the price/performance of advanced manufacturing hardware and the software will improve significantly. Technologies and methods that are currently not yet advanced enough, or that are currently too expensive to use, may begin to displace current methods in the MassBridge curriculum. Adding to this, the market is still in a "figuring-out" process for industry 4.0 and many of the technologies being fostered in the MUSA institutes. Every year, the amount of industry change will increase, and the disconnect between the MassBridge curriculum and the state of practice will widen.

As these technologies, and their market concepts, mature, MassBridge will need to incorporate the latest approaches to advanced manufacturing. However, MassBridge funding lasts only three years. Therefore, MassBridge will need to create mechanisms through which the curriculum can sense and respond to industry and market changes over time. Ideally, these mechanisms will be low-cost and self-sustaining. or will be able to build on future programs funded by ManTech, the Commonwealth, or other stakeholders. The entry of VR and AR technologies into manufacturing education can help to manage this process. Failure to keep up will relegate the MassBridge curriculum to an unnecessarily short lifespan. Overall, the updating of manufacturing programs needs to take place at business speeds of weeks and months, not academic speeds of semesters and years.

So, advanced manufacturing is an evolving field, with some technologies starting to enter workplaces ("closer-in") and others still in development ("further out"), as noted above. Since employer involvement is critical in keeping curriculum relevant to new advances, mechanisms for continuing to include employers and the full group of community colleges will be required.

14. Train the trainers: Existing faculty will need to stay up-to-date with new manufacturing developments to be able to teach it effectively

Advanced manufacturing is not only an issue of educating students it requires faculty education as well. Mechanisms will be required for updated training for faculty in the new and evolving manufacturing areas. Many industry-approved credentialing programs require that instructors themselves be certified in the processes they teach. Community college instructors may need to gain the appropriate certifications if they are to tie their programs to industry-recognized credentials. Beyond certifications, however, train-the-trainer programs can ease adoption by community colleges by reducing resistance from existing faculty or producing new faculty who can teach and scale the programs.

V. Models for Content Delivery

Employers in the U.S. do most of the workforce training. Many manufacturing firms, particularly SMEs, "hire for will, train for skill," as the phrase goes, and invest in years of on-the-job training for their workers.[28] They want steady workers who will show up on time, work hard, and collaborate well with others. These workers arrive with school-based *foundational skills* such as reading, writing, and basic mathematics, but typically need to acquire *industry-specific skills* (for example, machining), then *job-specific skills* (machining for particular products and production lines) as illustrated in the Department of Labor's Career One Stop Competency Model.[29] SMEs typically take on the training for both the industry-specific and job-specific skills and often have to divert their most productive and experienced employees to these training duties. This process is inherently inefficient, and these firms would benefit from more rapid and less expensive training.

Of course, more efficient training is possible. The training gap refers to the divide between firms that "hire for will, train for skill" and firms with training connections to community colleges, vocational schools, and collaborative programs, which provide a pipeline of graduates with relevant skills (See Table 2). The latter type tends to be larger firms that have the scale to invest in, and benefit from, these training connections.

Firms that rely largely on informal, on-the-job training are facing the consequences of the decline of the "manufacturing commons" – the ecosystem of supporting mechanisms that in an earlier period of more vertically-integrated U.S. manufacturing helped to transfer knowledge, provide training, and lend technical expertise. Without this ecosystem, as political economist Suzanne Berger has noted, SMEs tend to be "home alone."[30] Her research on U.S. manufacturers found that manufacturers without this ecosystem struggle to innovate and scale up new technologies as well as to train their workers. Creating connections to a renewed manufacturing ecosystem appears to improve the way manufacturing workers can develop new skills – it can improve efficiency and productivity.[31]

To reiterate, inevitably, employers will need to provide job-specific skills to their employees relevant to their particular production and product lines. But there are also a host of general manufacturing skills – the industry-specific skills - needed by workers before the job-specific skills come to bear, in manufacturing fields like machining, CNC operation, and welding. Currently, particularly at SMEs, the employer takes on the task of providing both the general and job-specific skills. However, if other institutions and collaborations could do much more of the general industry skill development, there would be much less training for the employer to have to undertake. This could dramatically cut the time for and improve the efficiency of SME training.

The MassBridge project, as shown in Table 2, aims to change the above designs by adding advanced manufacturing elements to the educational mix, above core manufacturing skills, with community colleges and vocational technical high schools supporting this new education step.

By providing training in a new core of advanced manufacturing skills, MassBridge can alleviate some of the training burden currently borne by employers.

Table 2: The MassBridge role in providing core advanced manufacturing skills for SMEs and larger employers [32]

MassBridge	MassBridge curriculum				On-the-job training (shadowing, reading company S&Ps)
Work & Learn collaboration (Typical of larger employers)	Traditional Manufacturing AA degree				On-the-job training (shadowing, reading company S&Ps)
"Hire for will, train for skill" (Typical SME approach)	Educational institution				On-the-job training (shadowing, reading company S&Ps)
	General Skills (e.g. reading comprehension, writing, basic math)	**Basic manufacturing skills** (e.g. principles of machining, measurement and testing)	**Core advanced manufacturing skills** (e.g. critical thinking, troubleshooting, data, integration, industry 4.0, robotics)	**Specialist skills** (e.g. fiber optic, additive manufacturing, robotics)	**Context-specific skills** (e.g. firm, product, production line, software tool)

Further progress is needed because a new generation of advanced manufacturing technologies in areas like digital production, flexible robotics and 3D printing is starting to enter the workplace and a new suite of advanced skills will be required for these new technologies. SMEs are already behind in productivity and efficiency, and part of the problem is the inefficiency in the current system most used to train their workers. Currently, this on-the-job training means reducing overall productive capacity, and training a skilled worker can take years. SMEs will fall even farther behind when global competitors and the larger firms they supply start to implement advanced manufacturing technologies. They now lack a good system for educating for current manufacturing skills, and this will only get worse when advanced manufacturing starts to scale

We already have a problem with training for current manufacturing skills; it will get much worse as we try to introduce advanced manufacturing technologies. We can make a distinction here. There is a "skills shortage" because we aren't filling the manufacturing positions that are opening up due to retirements and demographics. But there is also a "skills gap" because we aren't training for the oncoming skill sets that manufacturing will require.[33] So we need a much better system for educating in the industry specific advanced manufacturing skills. MassBridge needs to work on both problems, but is particularly focused on the "skills gap" challenge. The overall point is that firms will still need to educate for the job specific skills relevant for their particular product lines, but could we reduce the training load that firms need to provide by increasing the availability and quality of a more collaborative workforce education system for the general industry-specific skills, both for current and advanced manufacturing technologies?

This problem, and the inefficiencies it leads to, as well as some of the ways around it, have been detailed in a study of two New Hampshire manufacturing firms, one small and one large.[34] The small firm, with production that was low volume and high mix, had the entire training burden, both for industry and job-specific skills, and had to pull its best workers off production to train others. The training process was slow, painstaking and inefficient, and by shifting experienced workers to training, hurt productivity. The larger firm, because of its scale, had the ability to build an alliance with an area community college, agreeing to take some of its graduates in return for a general industry training program relevant to its production equipment that it designed with the community college. This produced a considerably more efficient training system. The larger firm was also able to systematize training at greater scale on site for job specific skills.

Since the training task is already shared, to varying degrees, by companies and education institutes, a collaborative approach seems key. Let's say that a new workforce training system could be built that relies more on collaborations with other employers and education institutions to benefit both small and large employers, and that enables training not only in current but advanced manufacturing skills? What would that system look like? There are ways manufacturers can develop and participate in consortia to improve training for their workforces. Some existing models from other states are described below. We focused our benchmarking on non-Massachusetts institutions so that MassBridge can benefit from these outside perspectives in developing its strategies.

1. Employer-led regional networks

Manufacturing historically has been regional, with companies and suppliers locating near each other to share infrastructure, a talent base, and technical know-how. In particular, supplier firms often share connections with the primes they supply. Because the U.S. thinned out so much of its industrial ecosystem in recent years, many firms are more isolated and "home alone," so partnerships with nearby firms that also face workforce needs is an option. In this way, they can share training costs and risks with each other. However, there is not a strong U.S. history of cooperation between potential competitors so alliances for regional training or technology development are not typical.

Cooperation between firms on training is difficult for a series of reasons. challenging for at least two related reasons. First, firms can be reluctant to undertake joint training initiatives for fear that other firms will poach their trained workers. The economic literature suggests that firms often underinvest in workforce education because of this risk that other firms will hire away their workers after they are hired, free-riding on their training investments. Second, firms often maintain that what they do is unique and requires firm and job specific skills, so they believe cooperation on training has limits. Despite these potential problems, there are examples where collaborations between firms on training in firm-led regional networks can work, demonstrating the benefits of employer cooperation in training.

For example, after a group of Ohio manufacturing leaders recognized their shared problems in finding skilled workers to fill open positions, they formed the Alliance for Working Together (AWT) 2002.[35] Initially, they began by sponsoring robotics competitions at local public high schools to locate an area talent pool interested in manufacturing careers. In 2019, AWT launched a joint apprenticeship program where five local firms each selected junior incumbent workers to attend weekly classes in CNC machining. The courses are taught by AWT members and are affiliated with a local community college. To move beyond a standard curriculum, they use Facebook feeds from leading machine tool manufacturers for students to learn about new manufacturing technologies.

Another example of employer-led collaborations is provided by the Chamber of Commerce Foundation. It has been developing a talent pipeline project with employers, (both manufacturing and non-manufacturing) that enables groups of regional employers to collaborate on and develop common job education needs, and then to negotiate jointly with community colleges and other education providers for development of courses and training that fit the needs set by these regional groups of employers.[36] A new job registry grew out of the data being developed on job position descriptions by employers. To implement the new system, building on lessons learned, the foundation has also organized a Talent Pipeline Management (TPM) Academy focused on developing the ability of local chambers to organize employer members and support talent supply chains. The TPM Academy is supported by a curriculum and related software tools that allow staff inside the foundation's regional organizations to implement cooperative talent solutions for their employer members.

2. Industry-led programs

The timetable for implementing the advanced manufacturing technologies evolving at the manufacturing innovation institutes is varied. As noted, some technologies are relatively close-in, beginning to move toward adoption by production companies. These include robotics, 3D printing, lightweight metals and digital production. Other technologies are still in an earlier development phase, farther away from adoption, such as biofabrication, photonics, functional fabrics and flexible electronics.

Industry-leading vendors have an incentive to train workers in their technologies. Better-trained workers can help to increase demand for their products. In some cases, making it easy to train workers in a specific toolset can lead employers and students to prefer one vendor over another

(Apple's heavy investment in K-12 education is a good example). As a result, vendors have already created curricula for some of the closer-in technologies, and these can be adopted without extensive additional development, especially where they use software and user interfaces are (at least de facto) industry-standard.

Some of these companies have already partnered with community colleges to develop full programs in their areas. While the American Welding Society (AWS), a non-profit, provides extensive welding training programs, including online programs, individual companies are also providers. For example, Lincoln Electric in Cleveland is a leading developer of welding technology, now also offering robotic welding capability. It has developed a series of welding training programs, at both fabrication and application levels, to accompany its product lines, including 13 modular certificates in a range of welding skills. It uses these to offer customized welding training to companies for upskilling incumbent workers. It also offers its curriculum to programs at community colleges. Lincoln's education materials include a comprehensive curriculum with lesson plans, labs, and virtual online welding systems. Lincoln uses NC3 (the National Coalition of Certification Centers) as an independent 3rd party certifier for its skills training programs. So, Lincoln has in effect created a network of employers and community colleges where it acts as coordinator, providing education content and industry certifications.

Other companies follow a similar approach. Fanuc, a leading industrial robotics company with its U.S. headquarters in Rochester Hills, Michigan makes flexible, adaptable and semi-autonomous robots. It works to align industrial needs with its robotics curriculum. Because robotics is new technology for many firms, it offers full training programs for its manufacturing customers' employees along with its products. It has its own robotics training center and has developed basic robotics education, both online and in-person, at two levels, for operators and technicians. Its third level is in systems and offered jointly with Rockwell Automation, the automation and process controls firm, since robotics and process controls require complementary skills and must be integrated. At this specialist level, the worker must fully understand the two systems and be able to undertake troubleshooting and problem-solving for both. Fanuc is also aiming at a fourth level for systems integrators who can integrate process controls, robotics, as well as a range of CNC and other equipment, which don't share the same programming systems. So, it is looking at a new icon-driven language for full integration. It uses NOCTI (the National Occupational Competency Testing Institute) as an independent, 3rd party credentialing organization with its own assessment system. This assessment includes both testing for robotics fundamentals and hands-on in-person evaluations, where experts undertake skill assessments using robotics and other equipment. Fanuc brings its robotics training programs to a network of community colleges that it works with closely on robotics, which also imbed its industry robotics certifications into their academic programs.

Rockwell Automation, headquartered in Milwaukee, a leader in automation and process controls, and is striving for a digital production Industry 4.0 curriculum. It has developed multiple levels of curriculum for workers and students. Levels 1 and 2 offer the fundamentals of advanced manufacturing and control systems while level 3 offers a coordinated curriculum in both process controls and robotics with Fanuc, as noted above. Level 4 is in ongoing development and is in Industry 4.0 skills, merging OT and IT for full smart manufacturing systems integration. Education is a major part of the company's offerings to manufacturing customers along with its equipment and it is very focused now on getting workers and students to this new level 4. Rockwell's education leaders see this as providing the decision-making process that companies need to decide what their IT and software infrastructure should be, how to develop it, and how to employ cybersecurity to protect it. They find that such companies need to look at the fundamental "whys" and "wherefores" of what they are doing, and implementing this rethinking takes a big push with well-trained employees applying a sound methodology and a significant level of critical thought. In Rockwell's view, this is a critical integration step, especially in a multi-vendor environment with a range of equipment. This connecting ability is the key skill they are now attempting to develop programs to train for. Rockwell has its own technology training centers, and extensive programs for sharing its curriculum with community colleges and state universities. Like Fanuc, it uses NOCTI as an independent, 3rd party credentialing organization. Rockwell also has its own Academy for Manufacturing where it is attempting to train 1000 veterans a year in automation and process controls. Siemens is another technology company involved in Industry 4.0 that offers standards and skills training and has used partnerships with education institutions to disseminate it.

The point here is that, where training curricula exist for closer-in advanced manufacturing technologies, it does not have to be reinvented. Existing high-quality curricula and programs can be incorporated into programs from community colleges and other education institutions. These four firms, Lincoln, Fanuc, Rockwell and Siemens, each of which has working alliances with community colleges, are leading examples of companies that have developed extensive curricula in advanced fields including robotic welding, robotics, automation, and Industry 4.0 systems integration that could be of interest to MassBridge. It should be recognized that these firms' programs will, of course, will tend to train for their company's equipment. This makes it more complicated for a community college or manufacturing institutes to adopt their training programs – do they want to train for a particular equipment brand, or should their training be broader? Yet if a particular firm's equipment is prevalent in a region, a community college may need to adopt its training programs to meet regional employer needs. Different institutions will make different choices, but the point remains that quality training material is available from industry equipment makers.

3. MUSA-led programs

Many advanced manufacturing technologies are still in development so the education content does not yet exist. The MUSA Institutes bring together two groups that can be very helpful in enabling skill development in their areas: companies working on the new technologies and education partners who are researching them. Particularly for new technologies that are farther out from implementation, the manufacturing institutes can play an essential role in creating curricula, skill roadmaps and credentials associated with their fast-evolving technologies.

The convening power of the institutes, their national reach, their access to the state of the art in their technologies, and their ability to invest in relevant programs can make them a powerful force for curriculum and credential development.

Some manufacturing institutes have developed a skills roadmap to nurture workforces skilled in their technology fields. ManTech has encouraged this as well as encouraging the institutes to develop education materials for its upcoming online platform for workforce education.

MassBridge is organized to draw on five manufacturing institutes for curriculum support – AIM Photonics Academy, NextFlex (flexible electronics), ARM (robotics), MxD (digital production), and AFFOA (smart fibers). These and the other institutes vary in the extent to which they have developed curricula and workforce roadmaps. They also vary in the approaches they have taken to develop their offerings, whether top down from the institute, or bottom up from their collaborators. Three efforts show some of the more effective approaches that the institutes have delivered.

A. AIM Photonics

A manufacturing institute that has been at the forefront of developing curricula for a fast-developing advanced technology is AIM Photonics Academy, the workforce education arm of the AIM Photonics manufacturing institute. Integrated photonics uses complex optical circuits to process and transmit signals of light, similar to the routing of electrical signals in a computer microchip. This technology will over time have a transformative effect on electronics, enabling much greater speed but, as noted above, is "further out" -- it is still in a development and early adoption phase. AIM Academy has developed a series of programs to enable this adoption for both engineers and technicians. AIM Academy:

- Has developed two courses now offered through MITx on the edX platform for online courses, on photonics integrated circuits and photonics fabrication and design, and has four more online photonics courses in development.
- Is creating a virtual lab for community college, college and graduate students in a computer gaming-based setting for these students to develop both integrated photonic circuits and systems, to support knowledge of both design and manufacturing.
- Has a "future leaders" summer program at three universities to train undergraduates in an intensive, 8-week program in integrated photonics.
- Has pilot photonics technician training certificate programs at two Massachusetts colleges and has developed the supporting 15-month technician-level curriculum, with a certification as well as college credit.

- Runs an integrated photonics “academy” program twice per year for in-depth, hands-on training for engineers at companies interested in implementing integrated photonics using advanced photonics equipment.
- Is preparing a series of VR modules for integration into photonics training programs.
- Has developed three teaching packages of curricula and supporting materials in the areas of integrated silicon photonics, photonic materials and photonic devices for use by educational institutions and companies.
- Has created a series of Ted-Ed videos on integrated photonics and its manufacturing infrastructure to introduce the field of photonics to those interested in pursuing it.
- Has eleven university partners and four community college partners in its various projects, as well as numerous participating companies.
- Is developing a workforce education roadmap which includes company hiring projections for photonics technicians and engineers.

It presents a good example of the kinds of multifaceted programs - both online and in-person, and at technician and more advanced levels - that a manufacturing innovation institute potentially could provide. ManTech has supported a range of approaches at the institutes; the AIM projects provide good examples of ManTech’s backing. Worth highlighting is AIM Academy’s systematic pursuit of advanced education technologies to assist the field in scaling up its training. These include online education courses and modules, as well as its development of VR modules for hands-on experience in designing and producing integrated photonics.

B. ARM: The robotics institute

ARM has worked with its industry members to develop material on competencies and “Knowledge, Skills and Assessments" (KSA) elements for the new generation of industrial robotics, which tend to be lighter, safer, more collaborative and with autonomous features. It found that its robotics industry partners had already developed curricula in this area so there was no reason for ARM to try to duplicate it. However, it found a wide variation in the quality of robotics programs that many educational institutions were offering, with some current and others not. It is therefore taking on an endorsement role for education institutions, primarily community and technical colleges, to evaluate their programs matching them to the lists of competencies that its robotics industry members have established. Where they meet ARM’s quality content and assessment standards, it will provide an ARM endorsement for their programs; where there are gaps ARM will work with the educators to improve their programs to meet their standard. This in turn, will assure both students and industry of the quality of program students complete. ARM is not implementing this program through a pilot program with some 20 community and technical colleges. ARM’s robotics education program offers an opportunity to MassBridge to draw from its curriculum and content evaluation efforts.

C. IGNITE: From LIFT, MxD, and America Makes

A third manufacturing institute program is IGNITE.[37] IGNITE is a program to train high school students as advanced manufacturing technicians. It was initiated by LIFT, the lightweight materials manufacturing innovation institute, in coordination with MxD, the digital manufacturing institute, and America Makes, the additive manufacturing institute. Amatrol, Inc. assisted in development and is a program and training equipment supplier for the program.

IGNITE aims to help students become highly skilled technicians who have the abilities needed to optimize manufacturing technologies, processes, and systems. It has a strong emphasis initially on employability skills, from reliability to team skills to problem-solving, business fundamentals and critical thinking. The curriculum modules can be combined into one, two or three year programs. Starting with a semester on materials science and systems, students then can engage for either a semester or three semesters in traditional and advanced manufacturing concepts such quality, measurement, controls, CAD/CAM, programming, and robotics. This can be followed by a third year that digs deeper into advanced manufacturing and materials topics. In addition to learning key manufacturing topics, students also gain project-based experiences built around real industry problems and challenges, as well as solid IT skills. Three components form the IGNITE curriculum, informing and building off each other to help students develop their skills in a dynamic learning environment:

1) Materials Science - a series of materials science modules are integrated into the foundational IGNITE manufacturing activities and other courses, such as math and science. Each module includes a kickoff brainstorming session and final presentation of learning, with activities scheduled in between.

2) Advanced Manufacturing Systems and Processes – this is the most significant portion of the IGNITE curriculum in terms of content and student time, and includes courses on three levels of advanced manufacturing which stretch across all three years of the program. These blend interactive multimedia learning with virtual simulations of the various manufacturing technologies to help students experience the topics in an immersive, project-based environment, and cover a side range of manufacturing areas, from CAD and robotics programming to programmable controllers.

3) Capstone Projects – the third year also features students working in teams on a capstone project that uses industry-specific new and emerging technologies and equipment to solve real-world problems. Student teams research ideas, develop multiple solutions, analyze and select the best solution, build a prototype, and evaluate their results.

IGNITE program elements could be incorporated in both community colleges and vocational technical high schools and are included in the database in section VI, below.

IGNITE is a good example of modularization in a curriculum – its modules, carefully developed with industry input - can be taken out and combined with other programs. Although developed as a three-year high school program, it can also be used, particularly its third year, in community colleges. Ivy Tech, the Indiana community college system, for example, has used IGNITE modules in its manufacturing programs. As defined later in this report, IGNITE covers the Level 20 range of course elements we have highlighted, but also reaches into the level 30 elements as well. The modular approach fits well with possible MassBridge approaches, and can be considered as new curriculum elements are being developed.

4. School-led collaborations

There is a more widespread approach to collaborations, which is to let an area community college lead the effort, in close cooperation with area manufacturers. These colleges already have the infrastructure to readily set up to manage education programs, courses, certificates and degrees and for managing student needs. This means employers don't have to build up a new education infrastructure, they can make use of an established one. Lower income students in community college courses can also be eligible for federal Pell Grant student aid, which enables, in effect, employers to shift the cost of much of the training. While community colleges will likely not educate for a firm's job-specific skills, they can take on the role of industry-specific training. Where the collaborations with industry are close it can be a more efficient model than employer education alone for industry-specific skills. And even the Chamber and AWT models noted above had connections to community colleges.

We have examined a series of model programs for education-led collaborations outside of Massachusetts that offer a range of noteworthy approaches and are highlighted below. Hopefully, these demonstrated examples can help inform approaches MassBridge may want to encourage.

A. Connecting closely with employer needs

Gateway Technical College in Kenosha, Wisconsin changed its manufacturing curriculum when Foxconn, the Taiwanese-owned firm that is Apple's leading contractor, came to town. Foxconn is building a next generation factory for building flat panels with applications in education, medicine and entertainment, with thousands of new jobs. The plant will help a region that was hurt when a major Chrysler plant closed. It will require a new kind of production, much more digital and smart manufacturing-based. Working not only with Foxconn but with other area employers that wanted to adopt more Industry 4.0 production, and also with Rockwell Automation which is also based in Wisconsin, Gateway developed new courses and new programs that last from 12 week certificates to full two-year degrees. It has worked to integrate its new manufacturing curriculum with high schools that teach foundational manufacturing skills, then these students come to the technical college for the smart manufacturing skills that Foxconn, local companies and Rockwell advised on. It has embedded industry-recognized credentials into its curriculum which are certified and assessed by NC3. As one company official put it, “Foxconn forced Industry 4.0 into our curriculum much faster than it would have otherwise happened.” Working with industry, they have also created a “train the trainers” program to educate technical college and industry instructors in the new Industry 4.0 curriculum and competencies. Gateway offers a good example of a community college adapting its programs to high-end production companies that employ its students. The educated workforce in turn becomes a sustaining factor for keeping area employers tied to the region.

B. Multi-faceted approach for incumbent, underemployed and new entrant workers

Asnuntuck Community College in Enfield, Connecticut offers an example of reaching these three worker groups.[38] Located in a region with strong aerospace primes, led by Pratt and Whitney and Sikorsky, their supplier SMEs were having difficulty obtaining new workers in recent years. Asnuntuck, with limited manufacturing equipment, was having difficulty meeting their needs. The school allied itself with a group of companies that belonged to the area aerospace manufacturing association. These firms were facing having to limit their production and hiring in the state or to shift activities out of state because of skilled worker shortages. Together, they persuaded the state’s governor to focus on manufacturing workforce needs. Working with the state and the area companies, Asnuntuck officials obtained one of the state’s four new $25 million regional centers for the latest advanced manufacturing equipment, which was located at Asnuntuck, and shared with a group of other area community colleges. Working with the area companies and the new equipment, Asnuntuck upgraded the training for community college students. It also developed new workforce education programs in advanced manufacturing with the area firms for upskilling incumbent workers at these firms. While community colleges frequently reach current workers, Asnuntuck often delivers these programs at the workplace with training that the employers co-design. So Asnuntuck’s manufacturing faculty go out to the aerospace primes to deliver training on their sites, as well as providing training for groups of employees from smaller firms at one of the group’s firms. If the firms don’t have access to the new advanced equipment the community college has at its new center, the employees use that center for training. At the community college students earn year- long manufacturing certificates or two-year associate degrees in a range of manufacturing skills. As part of these programs, they undertake paid internships at area companies where they enhance their general skills and also learn job-specific skills for these potential employers. This helps break down the “work-learn barrier,” the longstanding disconnect between education institutions and employer needs. Asnuntuck has also initiated a program with area high schools where students in their junior and senior years spend afternoons at the community college learning manufacturing skills and earning community college credit, which can speed them toward Asnuntuck certificates and degrees as well as jobs.

C. Developing short programs to upskill workers quickly

Monroe Community College in Rochester, New York, has a manufacturing curriculum for area students because of Kodak's production history in the region. It is developing a new training center for advanced manufacturing programs in such areas as automation, industry 4.0, advanced machining, big data, analytics, digital production, sensors and robotics.[39] To undertake this it is enlisting new faculty with current industry experience. The center will be more than an advanced equipment space, it will have career and job placement services and ways to track student competency progress. In parallel Monroe has been developing short, accelerated programs in such areas as precision machining and mechatronics with the new technologies built-in to these programs, that can be completed in 11 to 22 weeks. To develop these short programs, it has been reviewing its one and two-year certificate and degree curricula and cutting all but the critical technical content. These short programs are developed in consultation with area industries based on key competencies that are mapped to industry needs. All lead to what Monroe terms microcredentials – certificates in specific skills that can be stacked with other certificates toward degrees. Monroe is finding that its short programs have a very high completion rate because these depart from the usual cafeteria menu approach to college courses and eliminate course choice, which reduces student confusion. Students in the short programs are with a set cohort for fixed common programs in an intensive daily program, and teamwork evolves with students helping each other. The school has also found ways to provide federal student aid through Pell grants to students in these short programs since students are making progress toward an eventual degree required by Pell.

Another community college developing these short programs is Valencia College, with 75,000 students on six campuses in the Orlando, Florida area.[40] It found its two-year degree programs were not reaching a key segment of the region's population: those in lower-end service sector jobs earning the minimum wage with no benefits, limited job security and families to support. These students lacked the time for a two-year program. So Valencia created an advanced technology manufacturing center with equipment contributed by area companies and instructors with recent industry experience. They offer 10 to 20 week programs in core manufacturing skills such as CNC machining, welding and mechatronics. Valencia is rapidly growing the program in manufacturing as well as other fields and has been able to promptly place graduates in jobs in the area's growing "Space Coast" and defense manufacturing sector, with starting pay at over $20/hour and benefits. These jobs place students onto the first rung of quality job careers. Valencia offers stackable certificates for these short programs with credits that can lead to degrees. Monroe and Valencia are not unique; short certificate programs that carry degree credits are being offered a growing number of schools.

Manchester Community College in Manchester, New Hampshire has developed innovative programs working with area robotics and technology companies that lead to both degrees and shorter term certificates. New Hampshire's six community colleges have divided up advanced manufacturing fields so that each school has programs that focus on some areas. This sharing of the responsibility means that each school doesn't have to have all of the advanced equipment and faculty to teach all the fields. This helps schools budget for the advanced equipment and faculty expertise that fits their specialty. Manchester (MCC) has focused on advanced mechatronics and robotics and has shorter certificate programs in these areas, as well making these programs part of degree programs. It works closely on curriculum development with two advanced manufacturing institutes, ARM, the robotics institute, and ARMI, the biofabrication institute. It has worked with the NSF ATE programs in Florida (FLATE) and in Connecticut to meet its specialized equipment needs. It has also developed the ability to mix and match its courses so that course modules can fit an employer's specific needs. And it has developed an incumbent worker training program with area companies using this tailored approach to meet specific employer needs for expertise. MCC relies on online elements embedded in its courses to create flexible programs for its students which can be completed on an accelerated basis if a student is ready. Its shorter programs offer credits that can be staked toward degrees.

D. Replacing legacy material with updated competencies

One example of updating legacy courses and content was Monroe Community College, which we described earlier. School leaders found that by stripping out some of the content originally meant to address the needs of Kodak's manufacturing processes, they were able to easily pivot some of those lessons into current advanced manufacturing processes without having to disrupt and change the entire curriculum. When trying to make room in programs for new advanced manufacturing content, a first step should be to examine existing content and remove topics that are no longer essential, but may have remained as a legacy to prior generations (or prior teachers) of the material.

E. Combining community college and high school with apprenticeship programs

Trident Technical College in Charleston, South Carolina provides a model for how to reach new entrant workers.[41] It breaks down the barriers between learning and work, integrating the two by linking high schools, a community college and area companies. The program begins in a student's junior year with morning courses in high school that emphasize science and math, technical courses in the early afternoon at the community college, and part-time work at an area company in later afternoons during the school year and full time work during summers and holidays. Wages generally start at around ten dollars an hour and increase as apprentices build experience. Apprenticeships like this shift students out of a high school environment and into a more mature context, studying with adults at the community college and working with adults at their companies. The programs can lead them directly into solid jobs and careers that can also fund further higher education. They graduate high school with a diploma and credits that take them to near completion of a year of technical college, and a Department of Labor or other skill certification. The program was first formed by a group of area small manufacturing firms working closely with Trident Tech, and it relies on close collaboration and support from the area Chamber of Commerce. Trident provides the links to the area high schools and the needed administrative infrastructure for all the participants. South Carolina's statewide apprenticeship program at the community college level, and Charleston's newer youth apprenticeship program, rely on established Department of Labor registered apprenticeships. Other work/learn programs are more internships and what could be called "apprenticeship light," but the key to all is closely connecting work and schooling. A number of states now have apprenticeship or working internship programs between employers and education institutions in manufacturing, including Tennessee's Career Pathways, Kentucky's FAME, Michigan's MAT2, and North Carolina's and Wisconsin's youth apprenticeships.

F. Improving completion rates

A continuing problem at community colleges is low program completion rates – often only a third of entering students complete their programs. One critical cause is that many students are underprepared and must take remedial courses in separate programs before they can enter college-level programs. Many get bogged down and never get past the remedial courses. This problem has largely been solved in the network of twenty-seven Tennessee Colleges for Applied Technology (TCATs) spread across the state that offer seventy career programs, including in manufacturing. These lead to certificates and associate degrees and also offer specialized training for skills needed by larger area employers.[42] The TCATs approach is to have all students take courses that prepare them for the college-level work so that no one gets singled out as needing remedial help. These courses are also directly connected to the student's chosen career field, so students see the links between the remedial work and work they want to do. At the same time as their remedial coursework, students start their career technical education courses. All students therefore get right into their chosen career courses so they can see their career opportunities from the outset. Coupled with the TCATs' known high job placement rate, this makes the career opportunity very real—it's not a dim light at the end of a long remedial tunnel. Students have individualized remedial learning plans and based on these have a mix of classes, online exercises, and access to mentoring at a learning lab open day and night. Each student pursues this remedial foundations program at his or her own pace. This is also a blended education model combining online and personal instruction; it's competency-based learning, with students mastering a series of stages and skills. The great majority of students complete their foundations programs shortly after their first trimester, and only a handful have not done so by the third trimester. This approach is effective system-wide. The completion rate across the TCATS is 81%, with job placement rates into the student's field of study at 86%, far above these rates at most community colleges.

5. State-driven support for education / employer consortia

We have reviewed two basic approaches for manufacturing workforce education consortia, firm-led networks and education institution-driven collaborations. We have also examined a series of best practices that can be applied in these networks and collaborations. This leaves open the question for how these approaches could move beyond a modest number of model programs toward more widespread acceptance. Employers and education institutions can lead manufacturing education consortia but these can also be driven at greater scale by state efforts. States, with their control over public education, labor programs and ties to employers could play a significant scale-up role. ManTech saw this opportunity to promote state planning and implementation efforts for advanced manufacturing workforce education using MassBridge as a pilot project, and potential model for other states.

But states face barriers to undertaking this. One of the deeper problems in workforce education is that the major federal programs supported by the Departments of Education and Labor are not well connected and generally don't reach incumbent workers. Because the federal programs are the major source of funding for state workforce and community college programs, they also drive how the states, in turn, organize their own programs: state implementation follows federal patterns. The result is a disconnect at both federal as well as state levels. States, though, are essential workforce actors.

Massachusetts has attempted to solve these disconnects at the regional level and provides an example of state leadership in integrating the federal programs. In 2015, the governor, after hearing about workforce problems faced by the state's manufacturing employers, created a "skills cabinet" with the secretaries of the three state departments involved in workforce matters, Education, Labor and economic development. The skills cabinet meets biweekly and makes program decisions jointly: all three member departments must approve any new workforce-related program from the constituent departments. They work to coordinate across and unify the federal programs. A key state economic development focus is advanced manufacturing, which it sees as critical to its manufacturing sector. The work coordination at the governor's cabinet level is replicated at the local level. The MassBridge project is an important part of this state effort, and involves close coordination among the state's workforce boards, community colleges, economic development, and the manufacturing extension program.. Although the integrated workforce approach across state agencies should help MassBridge, the state faces other challenges in this project. For example, Massachusetts community colleges are all independent entities, so how could an advanced manufacturing curriculum delivery system be developed and applied statewide?

Various efforts in other states provide examples that could inform MassBridge's efforts. Using their control over state education and labor programs and their economic development ties to regional employers, other states have tried to provide a critical scaling element in getting best practices and new models adopted in their states. Relevant approaches in four states are noted below.

A. Connecticut: regional equipment sharing

Community colleges often have to scrounge to find modern manufacturing equipment to keep up with industry training needs. Connecticut, concerned with a manufacturing workforce shortage for its aerospace industry and facing a major scale-up in its submarine production sector, established four $25 million advanced manufacturing technology equipment centers at four community colleges in different regions of the state.[43] Asnuntuck Community College, noted above, hosts one of the centers. In turn, it has created regional groupings of community colleges to share these centers. The state has an integrated system of community colleges, so joint curriculum development in manufacturing can be organized to take advantage of this new advanced equipment.

B. Florida: Integration of a technical education development system that reaches across community colleges with a Manufacturing Extension Program linked to SMEs, and with the state's workforce development programs.

Florida has integrated the efforts of three critical programs for workforce education in the state, Florida Advanced Technology Education (FLATE), its collaborative program for manufacturing education across its community colleges; CareerSource Florida, its network of federal Labor Department-funded workforce development boards that manages workforce policy and investment; and FloridaMakes, the state's Manufacturing Extension Program that supports new production processes in its manufacturing SMEs and has support from the federal NIST program.[44] FLATE has received widespread recognition for creating an industry-defined and industry-endorsed two-year engineering technology degree that integrates national skill standards and is now offered in twenty-three of Florida's twenty-eight state colleges and community colleges; enrollment in the degree reached two thousand in 2018. It has developed frameworks for twenty different certificates within the engineering technology associate degree and ten specializations in manufacturing skill areas offered at these schools. All this was done in collaboration with manufacturing companies, trade associations, and government agencies across Florida. FLATE's industry and community college partners leveraged more than $80 million in state and local workforce funding for its programs. The engineering technology associate degree program prepares students for skilled jobs in manufacturing and other high-technology industries. Students in the first year take classes in introductory computer-aided drafting, electronics, instrumentation and testing, process control and materials, production quality, and safety—core skills that align with the national MSSC's portable production technician certification that many Florida manufacturers recognize. In the second year, students focus on a technical specialization. A valid MSSC credential also translates to fifteen credit hours for the engineering technology technical core in any of the schools offering the degree in the state. So, the credentialing works both ways: having the MSSC certification translates to credit at the state's community and state colleges, and the degree translates into recognized MSSC job qualifications. FLATE also runs a training program supported by CareerSource Florida's Quick Response Training grants; since the 1990s, these have assisted seven hundred plus Florida employers train more than 120,000 employees in specialized fields.

FloridaMakes, as the state's Manufacturing Extension Partnership, works to bring technology and process advances to Florida's small and midsize manufacturing firms and, with the state's fourteen regional manufacturing associations, is developing an overall strategy for the state's growing manufacturing sector. A major goal is to significantly increase the productivity of that sector; the state ranks thirtieth in productivity in the U.S. Part of all this involves connecting the dots with FLATE through a merger that will link the manufacturing certificate programs at the state's community colleges much more directly to manufacturing industry workforce needs and employment. Workforce education is at the center of a strategy to raise manufacturing productivity: a talented workforce ready to work with the latest technology advances is the best way its director sees to grow productivity, and the much more direct link between the state's small manufacturers and the community and state college programs initiated by FLATE is the way, he believes, to achieve this. Together, they are now working to expand their mission to include a big new area - apprenticeships.

The Florida programs indicate how integration of its community college technical education development program, its labor workforce programs, and its Manufacturing Extension Program with its ties to SMEs can benefit the state's manufacturing economy.

C. Ivy Tech: Systemwide standardization of community college programs

Indiana offers a different model for workforce education coordination. Ivy Tech is the only community college with many campuses across Indiana which are singly accredited. Twenty-five years ago, there were still very different community college curricula in different areas for different campuses. Now there is a unified curriculum. Ivy Tech uses the online learning management system Canvas as the shell in common for all Ivy Tech campuses, which enables shared resources across all schools, where all the system's faculty and students have common access. This helps assure basic uniformity and quality across campuses – a class in Madison, Indiana for example has the same resources as Fort Wayne.

But there can be variation in course mix to meet regional company needs. For example, Caterpillar, a major regional employer, the area campuses can vary up to 30% of their course content to meet regional needs. So the system is not as ironclad as it first appears – there is flexibility in model

Indiana is one of the country's strongest manufacturing states. So Ivy Tech has 22 campuses with manufacturing programs, with 22 manufacturing labs with manufacturing equipment. This means, too, that there are 22 deans and 44 program chairs in manufacturing, in total, for these campuses. Concerning industry input, each campus has a program advisory board that feeds responses to faculty, led by lead-program chair, and this group meets twice a year specifically to upgrade curriculum. Industry also provides teams of mentors for each campus program. This advisory mechanism means that schools can emphasize certifications that the companies are interested in. NIMs SACA and other certifying organizations work with Ivy Tech schools on the certifications they want to embed in their academic credentials.

Ivy Tech also has a growing apprenticeship "work/learn" program. It is also implementing Industry 4.0 curriculum with industry support - it is one of the few schools that now offers a degree in Industry 4.0 fields. It seeks to create systems integrators rather than the "engineering technician" that some states are encouraging. This program goes well beyond how to work a CNC machine or maintain a PLC. It requires a full systems understanding. It has drawn modules from the IGNITE program for its program.

While the centralized approach of Ivy Tech differs from Massachusetts' community college organization, it still offers some important lessons. The standardized modular structure of its curriculum allows for regional variation to meet needs of regional manufacturing employers. Ivy Tech executives told us that there is approximately 30% regional variation in the curriculum. On the other hand, the centralized approach gives employers confidence in the quality of the Ivy Tech program. They know exactly what educational background any Ivy Tech graduate has. But there is still room for regional flexibility to meet regional needs. The cross-campus online system helps assure the availability of quality courses and content across the state. The central importance of connecting with employers is another lesson from Ivy Tech – they are involved in the curriculum development so they know what they are getting when they hire Ivy Tech students. And this involvement has helped lead to a strong Industry 4.0 curriculum across the state.

D. Ohio: State-wide coordination of independent community colleges

Ohio has a system of independent community colleges with their own curricula and a series of different manufacturing regions around the state focused on different product lines, from automotive to aerospace to rubber products to machine shops This is somewhat analogous to Massachusetts, with its independent community colleges and different regional manufacturing economies. How does Ohio get coordination across its evolving workforce education system? The Ohio Manufacturers Association (OMA) has a major workforce education emphasis, which has been ongoing and has strong leadership for education programs from industry. Reflecting the different manufacturing sectors in different parts of the state, it has chapters in different regions, but OMA itself pulls together these strands to present a coordinated and uniform perspective to the state government and the governor on manufacturing workforce program needs. When community college curricula are developed, OMA is at the table with community colleges, providing industry input and perspectives on an ongoing basis.

If the state's manufacturers are coordinated on workforce education, how does coordination work across the state's independent community colleges? Lorain County Community College, one of the state's leading schools, obtained a U.S. Department of Labor TAACCCT grant some five years ago to work to develop a coordination mechanism for the state's community colleges. The result was Ohio Tech Net which also works very closely with OMA. Interestingly, the LIFT manufacturing institute also played a significant role in funding and supporting these community college and industry collaborations.[45] It has become a program and curriculum clearinghouse for all of the state's community colleges. Representatives of all of these schools meet biweekly, enabling their schools to share best practices and new manufacturing curricula. For example, industry-accepted credentials that can be offered with academic degrees and certificates are a need at the state's community colleges. Ohio Tech Net, OMA, and Lorain teamed up for an evaluation of some 3000 credentials manufacturing available for the range of manufacturing skills, and selected 300 that were of most interest to industry, reflecting their different production regions. Ohio community colleges now choose from this group in offering industry credentials embedded into their academic programs. Both these programs offer potential models to Massachusetts as ways that community colleges can coordinate with each other, through Ohio Tech Net, and with state manufacturing employers, through OMA.

While all different, these examples offer important lessons on how states can support advanced manufacturing education. Opportunities include 1) equipment sharing across clusters of community colleges; 2) integration of state workforce development, community college education institutions teaching technical education, community college collaborative technical curriculum development, and state SME workforce needs; 3) standardization across community colleges, while enabling modular reconfiguration for local needs; 4) voluntary coordination across independent schools and employers.

6. Best practices behind these examples

Whether employer-led, vendor-led, school-led, or state-wide, the programs described above have created effective ways to build programs that provide advanced manufacturing skills through collaboration between educational institutions, employers, and often other parties. They enable firms to develop connections for training, and schools to provide connections for industry input, and get better exposure to the manufacturing ecosystem. What, then, are the underlying rules - the best practices – that models discussed above and other strong programs follow?

A. ***Break down the work / learn barrier.*** In all of the programs delineated above, employers and education institutions collaborate closely on both content development and content delivery. Strong programs offer a work component along with educational instruction, which can range from internships to formal apprenticeships.

B. ***Employers should collaborate with each other.*** Stand-alone programs where individual firms provide their own training are inherently inefficient; it's better if groups of firms share the costs and risks of workforce education. Better still is where primes and their regional SME suppliers can band together since efficient advanced manufacturing requires its adoption across supply chains. In turn, employer groups can link to education institutions - community colleges, technical high schools, state universities and state education and labor programs - for additional synergies. Education institutions can help manage the infrastructure for these consortia, shouldering much of the administrative burden.

C. ***Reach new entrant, underemployed, and incumbent workers.*** All these groups must be reached so programs need to extend to a mix for these participants. If an institution – a community college or employer consortia – can reach all three groups, they become reinforcing. A program for incumbent workers requires close ongoing contact with employers, with training that often can be delivered at an employer's workplace, which helps keep programs for all students current with industry needs, for example. And community college or employer programs can also reach high school students, helping to break down the work/learn barrier and linking high school students to college opportunities. Community colleges often partner on training with Workforce Development Boards, and that can be expanded and include advanced manufacturing skills.

D. ***Embrace certificates and shorter-term programs.*** In contrast to offering only full degrees earned in a fixed period of time, educational institutions should be encouraged to provide certificates, based on acquired competencies, that can accumulate to degrees. Certificate programs can help workforce education to fit students with limited time availability and employers with particular skill requirements. Degrees that take two years or more will still be needed but can be based on a series of related, stackable credentials. This, in turn, can enable short programs that help workers get required skills and employment earlier, plus a pathway toward additional skills or a degree, as desired.

E. ***Embed an industry-recognized credential into education institutions' certificates or degrees.*** Academic credentials are not enough. Many employers increasingly want the assurance of skill knowledge that an industry-approved and accepted credential provides. It creates an additional and parallel pathway to help students toward employment. It also ensures that academic programs are relevant to actual industry needs.

F. ***Ensure access to advanced manufacturing equipment.*** Employers want students who have actual experience with the latest production technologies. Because of the cost of equipment, there is a significant challenge in getting students hands-on learning, particularly with advanced equipment. One approach, noted in the Asnuntuck Community College example above, is for a state to create regional technology centers shared by consortia of community colleges, high schools and employers. In addition to providing efficient student access to equipment, providing companies access can help them test and experiment with new equipment, evaluating how it can improve their production process and assist in training for their workers.

G. ***Apply new education approaches that can scale.*** Offerings with new content can be blended, combining face-to-face with online education, which can help expand their reach to much higher numbers of students. Hands-on learning remains critical, but actual equipment can be supplemented with advanced technologies, including computer gaming-based courses and Virtual Reality and Augmented Reality (VR/AR) technologies.

H. ***Create programs that are eligible for Pell Grant funding.*** The federal Pell Grant program for student aid was set up to promote college degrees not workforce education, but if workforce credentials are stackable toward degrees, a number of schools have found ways to make these programs eligible for Pell grant support. Without a sustainable means for funding this education it will not be enduring, so connecting students to Pell Grants is an important step.

I. ***Create cross-state industry and community college coordination mechanisms.*** Ohio has a state-wide organization for its manufacturers, as well as a working consortium of its independent community colleges, that work together to implement manufacturing workforce education programs and update them. This ongoing industry and school collaboration is key to developing new programs and keeping them current.

Lorain County Community College in northeast Ohio is an example of a community college that embraces many of these approaches, so offers MassBridge a particularly relevant model.[46] In keeping with the need for short programs and stackable credentials, Lorain offers numerous specific certificates in particular manufacturing skills, from welding to automation, of around 16 weeks duration, which are stackable to lead to 1-year certificates and 2 year degrees. Lorain has been adopting what it calls “acceleration strategies” to move students more quickly through programs that are organized around specific skill competencies.

Lorain builds in industry certifications into its academic programs, for example from Fanuc (for robotics), Rockwell (for automation) and Lincoln Electric (for welding). Working with the state of Ohio it participated in a program that evaluated some 3500 industry credentials and narrowed the list to 309 particular industry credentials for use in the state’s community college programs, which Lorain uses. It is also working with five manufacturing innovation institutes on advanced manufacturing credentials. As a culminating degree, it is developing an applied baccalaureate degree for applied, skill-based technologist training as opposed to an engineering degree or 2-year degree technician training.

Through its “learn and earn” Lorain has its students working with employers as they work on credentials. To help students get through its programs, it has a wrap-around approach to student services; they help students with financial aid, remedial work and career and job placement support. It has a new one year program for incumbent workers in the new advanced manufacturing skills, so they can obtain perspectives on manufacturing’s future. It also has ties to high school programs, with partnerships with the county’s high schools in a “college credit plus” program that creates pathways from high school to Lorain. Behind all these efforts is a strong relationship with the Ohio Manufacturers Association (OMA), which assures close connections with industry for its programs. This effort also includes the Ohio Tech Net, which Lorain used a Labor Department grant to form, with the state’s other community colleges and with OMA. This effort includes a new apprenticeship program with OMA members.

Table 3: Noteworthy Programs

Program		Best Practice: Break down the work / learn barrier	Reach new entrant, under-employed, and incumbent workers	Embrace credential-ing and shorter- term programs	Embed an industry-recognized credential into certificates or degrees	Ensure access to advanced manu-facturing equipment	Apply new education approaches that can scale	Create programs that are eligible for Pell Grant funding	Develop cross-state industry and community college coordination mechanisms
Employer-led regional networks	Alliance for Working Together (AWT)	✓	✓				✓		
	Chamber of Commerce Foundation	✓							
MUSA-led programs	AIM Photonics	✓	✓		✓		✓		
	ARM	✓					✓		
	IGNITE	✓	✓			✓	✓		

School-led collabor-ations	Asnuntuck Community College	✓	✓		✓	✓			
	Monroe Community College			✓		✓		✓	✓
	Valencia College		✓	✓					
	Manchester Community College (NH)			✓					
	Trident Technical College	✓			✓				
	Tennessee Colleges for Applied Tech (TCATs)	✓		✓			✓		
	Gateway Technical College	✓	✓		✓				
State-driven	Connecticut		✓			✓			
	Florida (FLATE)				✓				

State-driven (continued)	Indiana - Ivy Tech	✓			✓		✓		
	Ohio Tech Net / OMA / Lorain County Community College	✓	✓	✓	✓		✓		
Industry-led programs	Lincoln Electric	✓	✓		✓				
	Fanuc	✓	✓		✓	✓	✓		
	Rockwell Automation	✓	✓			✓			

VI. Identifying Contents of Advanced Manufacturing Curricula

1. Building a Database of Existing Manufacturing Programs

We have now reviewed a series of effective content delivery models, as well as best practices derived from the case studies. However, content delivery requires content. So an additional major question remains: What should the content of advanced manufacturing education programs skills be?

As the suite of new manufacturing technologies (which DoD has been supporting through its manufacturing innovation institutes) evolves, new educational content is required to train the workforce in the skills for those technologies. And yet, as we described in the challenges section, there is a wide diversity of manufacturing education programs, and even disagreement about what the term "advanced manufacturing" means.

To identify an initial list of contents for the MassBridge curriculum, we synthesized data on existing programs. We built a database containing two types of manufacturing programs: academic degrees[1] and industry certifications/competency models. The rationale for including these two types of programs was simple: we assumed that the content of certifications and competency models represented the specific skills sought after by the manufacturing industry, while the content of the academic degrees represented the educational system's approach to meeting those needs for their local business environment. One goal of this benchmarking effort was to identify areas where the two perspectives might not be so well aligned, indicating a gap in one side or the other.

The programs in our database were selected for one of three reasons: (1) they were recommended to us by an expert informant during the interview process, (2) they are local to Massachusetts, or (3) they were found during an internet search for programs with an explicit Advanced Manufacturing focus, or an explicit "technologist" focus. Specifically for certification and competency models, we relied on two of the U.S. Department of Labor's CareerOneStop services, Certification Finder and Competency Model Clearinghouse, to ensure that these programs were legitimate.

The full list of programs used in this project can be found in Appendix A.

The programs in the database were further classified into levels based on the "advancedness" of the manufacturing career that they prepare for, based on the program name and stated focus.

[1] These are almost exclusively associate degrees, with the exception of LIFT's Ignite Advanced Manufacturing Technician high school program because it is modular, and some community colleges have adopted its modules, particularly from its third year programs.

These levels reflect the three main employment opportunities that emerged from data analysis and interviews:

Level 10: Manufacturing Technician

- o At level 10, students would learn the basic fundamentals of manufacturing. Upon completion of this curriculum a student might enter the workforce as a general technician.

- **Level 20**: Advanced Manufacturing Technician
    - o At level 20, students might learn the same basics of manufacturing as level 10 but would also include a broader level of advanced technologies integral to automated manufacturing. Upon completion of this curriculum a student would succeed as an advanced manufacturing technician.

- **Level 30**: Specialized/Connected Advanced Manufacturing Technician
    - o This level includes programs that are concerned with any of the six branches of manufacturing singled out by the Manufacturing Institutes included in the MassBridge program:
        - Integrated Photonics
        - Robotics
        - 3D/Additive Manufacturing
        - Note: we found no associate degrees or certifications exclusively dedicated Flexible Hybrid Electronics, Functional Fabrics, or Lightweight Materials
    - o In addition, this level also includes programs that have an explicit focus on connected manufacturing systems, such as Industry 4.0 or Mechatronics programs.

2. Analysis of Existing Manufacturing Programs

To characterize the content of these programs, we entered the list of courses in each academic degree along with their full descriptions, and the list of competencies or subjects needed for each of the certifications and competency models. Because the language used to describe these requirements varied highly across programs, we needed a way to capture the subjects and skills they addressed in a standardized manner. To this end, we labeled each of the courses and competencies with one or more topics from a list of about 145 standardized topic tags.

This list of topics was created and updated throughout the coding effort, with each round of coding contributing to simplifications or expansions to the list, thus requiring a new round of coding for topics to match the content of the new list. Two coders were involved in the coding process. The final list of topics can be found in Appendix C.

Once each course and competency was tagged with the appropriate topics, we used this information to identify "core" lists of topics that characterize the content of programs at each "advancedness" level of manufacturing. Indeed, determining which topics were consistently present across the programs within a level allows us to approximate the subjects and skills required to succeed for the occupation associated with that level. To this end, at each level of advancedness, we identified the topics that were addressed by the highest percentage of programs overall and the topics that were addressed by the highest average percentage of both certifications and academic degrees. This second metric, the highest average percentage, gives equal power to the industry-driven certifications / competency models and the academia-driven degrees, even when there is an uneven number of either type of program in the database. We combined these two lists to create a core list of topics for each level of manufacturing. The full methodology for this process is described in Appendix B.

It should be noted that this process will not yield precise, nor permanent, answers. The analytics are a function of the programs included in the database, and the richness of content available for each program. Some topics, especially those associated with traditional manufacturing, are very well represented, while some of the most advanced topics, such as biofabrication, are not represented at all.

As such, the analysis presented here represents a first, and non-final, set of curricular elements, based on systematic analysis of the existing data. We will need to adjust the elements at each level based on further discussion with the curriculum development team, as well as industry and academic experts. However, we recommend it as an important empirically-based approach to complement discussions in interviews and workshops. It also provides links back to existing programs so that designers can examine those program materials as they build or curate new courses.

In the section below, we will share the content lists for level 10, 20, and 30 curricula separately. Then we will compare the lists in a single table to show what is added or removed in moving to successively more advanced levels.

3. Analysis Findings

A. Level 10: Traditional manufacturing technician programs

Table 4 below shows the core topics that were found to be the most prevalent across Level 10 programs, which prepare for careers as traditional manufacturing technicians. In addition, the table displays which of these topics were addressed in a selected set of exemplary programs. The topics above the horizontal gray line are part of the core we derived through our analysis, while the topics below the line did not make it into the core but were still prevalent enough to warrant consideration. For ease of visibility in this table, we removed items that were less prevalent, although we can provide the full list as needed.

We can bucket these topics into four larger categories: human skills (important non-technical skills, sometimes called "soft" skills or employability skills), general education, industry-specific technical topics, and other technical topics not specific to manufacturing.

As shown in the table, Level 10 programs usually require a number of human skills: professional skills (which typically designates basic professional behavior, such as showing up on time or treating others with respect), critical thinking, problem-solving, communication (either written or oral), and understanding of ethics.

In terms of general education topics, we find that Level 10 programs tend to require lower-level mathematics (e.g. algebra, geometry, or trigonometry), basic research abilities, and reading comprehension skills. Although it did not make it into the core of most common topics, introductory physics (e.g. mechanics, statics, kinematics, or electromagnetism) is also a fairly popular subject across these programs.

In terms of industry-specific topics, Level 10 programs tend to cover knowledge of a number of high-level features of manufacturing such as safety issues, approaches to quality (including statistical process control and statistical quality control), manufacturing processes and their integration into manufacturing systems, control systems, and the materials that are typically used in manufacturing. In terms of specific skills, these programs often require the ability to create and interpret blueprints and other technical drawings, an understanding of electricity and electronics, knowledge of geometric dimensioning and tolerancing (GD&T) and basic measurement systems, knowledge of CAD and how it fits in computer aided manufacturing, machine tooling (as well as hand tools, although they are not in the core), and the ability to operate both CNC Machines and manual machines. Finally, the Level 10 programs do not tend to include non-manufacturing technical skills.

Note that we included MACWIC in the figure below because it was created by the Commonwealth of Massachusetts as a potential standard for manufacturing skills. However, we did not have access to granular information for the MACWIC Manufacturing Technology Pathway Certification, and it is possible that this credential covers more skills than the table indicates.

Table 4: Core Skills for Level 10 (Manufacturing Technician) Programs

	Top Level 10 Topic			Certs./Comp. Models		Academic Degrees	
	By Total Percent	By Average Percent	Overall Core	MACWIC Applied Mfg Technology Pathway	SME Mfg Technologist	Ivy Tech Community College AAS Industrial Tech. (Industrial Electrical Pathway)	Lorain Community College AAS Mfg Engineering Tech. - Computer Aided Machining
Quality	82	88	Yes	Yes	Yes	Yes	Yes
Technical Blueprints & Drawings	76	85	Yes	Yes	Yes	Yes	Yes
Manufacturing Processes	88	84	Yes	No	Yes	Yes	Yes
Professional Skills	71	81	Yes	Yes	Yes	Yes	No
Safety	71	81	Yes	Yes	Yes	Yes	No
CNC Machining	65	77	Yes	Yes	Yes	No	Yes
Manufacturing Systems	65	77	Yes	Yes	Yes	Yes	No
Research	88	75	Yes	No	Yes	Yes	Yes
Electronics	71	72	Yes	No	Yes	Yes	Yes
Basic Measurement	53	69	Yes	Yes	Yes	No	Yes
GD&T	53	69	Yes	Yes	Yes	No	Yes
CAD/CAM	65	68	Yes	Yes	Yes	No	Yes
Machine Tools	76	67	Yes	No	No	Yes	Yes
Communication	82	62	Yes	No	Yes	Yes	Yes
Lower-Level Mathematics	82	62	Yes	No	Yes	Yes	Yes
Manufacturing Materials	59	56	Yes	No	Yes	Yes	Yes
Systems Control	41	53	Yes	No	Yes	Yes	No
Statistical Process/Quality Control	53	52	Yes	No	Yes	Yes	Yes
Manual Machining	65	51	Yes	No	No	Yes	Yes
Critical Thinking	76	50	Yes	No	No	Yes	Yes
Reading Comprehension	76	50	Yes	No	No	Yes	Yes
Problem-Solving	59	47	Yes	No	Yes	Yes	Yes
Ethics	53	43	Yes	No	Yes	Yes	No
Production Performance	35	49	No	Yes	Yes	No	No
Fluid Basics	47	48	No	No	Yes	Yes	Yes
Fluid Power	47	48	No	No	Yes	Yes	Yes
Hand Tools	47	48	No	No	Yes	No	No
Introductory Physics	47	48	No	No	Yes	No	Yes
Mechanical Elements & Power	47	48	No	No	Yes	Yes	No

B. Level 20: Advanced Manufacturing Technician Programs

Table 5 shows the core topics that were most prevalent across Level 20 programs, which prepare for careers as an advanced manufacturing technician. In addition, the table displays which of these topics were addressed by a selected set of exemplary programs.[2] Again, the topics above the horizontal gray line are part of the core, while the topics below did not make it into the core but were still prevalent enough to warrant consideration, and less-prevalent topics were omitted, but available as needed.

In general, the analysis suggests that Level 20 programs require many of the same skills as Level 10 programs, but start to incorporate a range of more advanced technical skills as well.

In terms of human skills, communication, professional skills, critical thinking, and problem-solving remain core topics. However, ethics is no longer considered to be a core topic.

In terms of general education, a number of topics carry over from the Level 10 core: lower-level mathematics, research abilities, and reading comprehension. In addition to these, introductory physics has now become a core topic.

In terms of industry specific-skills, Level 20 programs tend to cover many of the some high-level features of manufacturing as Level 10 programs, such as safety issues, approaches to quality (now including quality control), manufacturing processes, manufacturing systems, and control systems (now including PLCs). Similarly, print reading, GD&T, CAD/CAM, electronics, basic measurement, machine tooling, and CNC/manual machining all remain central features. In addition to these, several advanced technical topics have also been introduced: robotics, instrumentation and sensors, mechanical elements and power, and mechatronics. Level 20 programs also tend to emphasize system-level skills such as maintenance and troubleshooting.

Finally, unlike Level 10 programs, Level 20 programs start to fold in non-manufacturing technical skills. For example, basic computer skills is a relatively popular topic (although it is not a part of the core).

[2] Note that, although we have concentrated on associate degree programs in our analysis, we included Ignite's Advanced Manufacturing Technician model here. We classified it as an academic degree program rather than a competency model because, unlike other certifications and competency models, it is defined by a curriculum structured to take place over two to three years. As described earlier, IGNITE is actually a high school program, but is modular, and some community colleges have adopted its modules, particularly from its third year program.

Table 5: Core Skills for Level 20 (Advanced Manufacturing Technician) Programs

	Top Level 20 Topic			Certs./Comp. Models		Academic Degrees	
	By Total Percent	By Average Percent	Overall Core	AMTEC Adv. Mfg Modules	DoL ETA Adv. Mfg Comp. Model	Gateway Technical College AAS Adv. Mfg Tech.	Ignite Adv. Mfg Technician (HS)
Safety	78	87	Yes	Yes	Yes	Yes	Yes
Technical Blueprints & Drawings	78	87	Yes	Yes	Yes	Yes	Yes
Communication	94	83	Yes	No	Yes	Yes	Yes
Quality	72	83	Yes	Yes	Yes	Yes	Yes
Electronics	67	80	Yes	Yes	Yes	Yes	Yes
Machine Tools	67	80	Yes	Yes	Yes	Yes	No
Manufacturing Systems	67	80	Yes	Yes	Yes	Yes	Yes
Instrumentation & Sensors	61	77	Yes	Yes	Yes	Yes	Yes
Basic Measurement	56	73	Yes	Yes	Yes	Yes	Yes
Maintenance	56	73	Yes	Yes	Yes	Yes	Yes
PLCs	56	73	Yes	Yes	Yes	Yes	Yes
Systems Control	56	73	Yes	Yes	Yes	Yes	Yes
Troubleshooting	56	73	Yes	Yes	Yes	No	No
CNC Machining	72	70	Yes	Yes	Yes	Yes	Yes
GD&T	67	67	Yes	No	Yes	Yes	Yes
Manual Machining	67	67	Yes	Yes	Yes	Yes	Yes
Manufacturing Processes	67	67	Yes	Yes	Yes	Yes	Yes
Robotics	67	67	Yes	Yes	Yes	Yes	Yes
Mechanical Elements & Power	44	67	Yes	Yes	Yes	Yes	Yes
Mechatronics Systems	44	67	Yes	Yes	Yes	Yes	Yes
Introductory Physics	61	63	Yes	No	Yes	No	No
Professional Skills	56	60	Yes	No	Yes	No	Yes
CAD/CAM	72	57	Yes	No	Yes	No	Yes
Critical Thinking	72	57	Yes	No	Yes	Yes	Yes
Lower-Level Mathematics	72	57	Yes	No	Yes	Yes	Yes
Research	72	57	Yes	No	Yes	Yes	Yes
Problem-Solving	56	47	Yes	No	Yes	Yes	Yes
Quality Control	56	47	Yes	No	Yes	Yes	Yes
Reading Comprehension	56	47	Yes	No	Yes	Yes	No
Basic Computer Skills	39	63	No	Yes	Yes	No	No
Hand Tools	39	63	No	Yes	Yes	No	Yes
Hydraulics	39	63	No	Yes	Yes	No	Yes
Pneumatics	39	63	No	Yes	Yes	No	Yes

C. Level 30: Specialized / Connected Advanced Manufacturing Technician Programs

Finally, we arrive at the Level 30 core. Table 6 shows the core topics that were most prevalent across these programs, which prepare for careers in either the specialized branches of advanced manufacturing or in highly connected, industry 4.0-related manufacturing. In addition, the table displays which of these topics were addressed by a number of exemplary programs. As the list of core topics for this level was longer than for previous levels, only core topics are shown.

It should be noted that there are far fewer level 30 programs or certifications. For example, we found full programs in robotics, mechatronics and Industry 4.0, as well as certificates in photonics and additive manufacturing, but none for three of the advanced manufacturing branches in MassBridge (i.e. flexible hybrid electronics, functional fabrics, lightweight materials). As a result, the analysis of core skills is biased by the absence of those programs. Still, the findings are aligned with information we gleaned from expert interviews.

As we learn of additional advanced programs, we can add them and re-run the algorithms. Where specialized advanced programs do not exist, we may be able to use lists generated by the EWD directors in each Manufacturing Institute, from the Roadmap effort in MassBridge, or through systematic interviews with experts.

Another peculiarity of this level is that it is characterized by a wide breadth in focus, such that many of the topics that are common across programs may be very basic, fundamental manufacturing topics. However, the remaining common topics will provide a window into the types of advanced skills that represent the future integrated manufacturing environment envisioned by industry 4.0 and similar frameworks, or represent the common advanced core that MassBridge aims to address. Meanwhile, many skills that are specific to specialized programs, skills such as bonding fiber optic cables, will be left for more specialized training programs..

Overall, the analysis suggests that Level 30 still has a lot in common with both Level 10 and Level 20 programs. However, a few crucial digital and automation-related skills start to characterize this vision of manufacturing.

In terms of human skills, the focus on professional skills, critical thinking, communication, and problem-solving remain from previous programs. In addition, this level introduces the more specific and technical human skill of scientific communication.

In terms of general education, the importance of mathematics has increased: probability and statistics as well as basic mathematics now accompany lower-level mathematics in the list of core topics. In addition, reading comprehension, and introductory physics carry over from the previous levels.

In terms of industry-specific skills, many of the usual foundational topics remain, such as safety, quality, manufacturing processes, control systems (including PLCs and now Process Control) and manufacturing materials. Similarly, print reading, electronics and electricity, basic measurement, manual machining, and machine tooling (and now hand tools) remain central features, as well as robotics, instrumentation and sensors, troubleshooting, and maintenance. Mechatronics is no longer a core topic, but this is not surprising because mechatronics is only one of several branches of level 30 programs, and such a specialized topic is unlikely to appear across other equally specialized branches such as photonics. Some core manufacturing topics such as CAD/CAM, CNC Machining, Manufacturing Systems and GD&T have also disappeared. Instead, a focus on fluid power systems emerges with the inclusion of both hydraulics and pneumatics.

Finally, the focus on automated manufacturing technology is clearer now as automated systems becomes a core topic, replacing manufacturing systems. Indeed, Level 30 programs have a clear interest in fostering digital skills such as basic computer skills, data management, and simulation. In fact, other popular topics that are not shown here because they did not make it into the core include connected systems, robot programming, production planning, and networks (all in 57% of all level 4 programs overall, and in 55% of programs on average).

Table 6: Core Skills for Level 30: Specialized/Connected Manufacturing Technician Programs

	Top Level 30 Topic			Certs./Comp. Models		Academic Degrees	
	By Total Percent	By Average Percent	Overall Core	DoL ETA Mechatronics Comp. Model	NIMS I4.0 Smart Systems Integration Specialist	Ignite Adv. Mfg Technician (HS)	Ivy Tech Community College AAS Adv. Automation and Robotics Tech.
Instrumentation & Sensors	100	100	Yes	Yes	Yes	Yes	Yes
Professional Skills	100	100	Yes	Yes	No	Yes	Yes
Troubleshooting	100	100	Yes	Yes	No	No	Yes
Communication	86	90	Yes	Yes	No	Yes	Yes
PLCs	86	90	Yes	Yes	Yes	Yes	Yes
Systems Control	86	90	Yes	Yes	Yes	Yes	Yes
Electronics	71	80	Yes	Yes	Yes	Yes	Yes
Introductory Physics	71	80	Yes	Yes	No	No	No
Problem-Solving	71	80	Yes	Yes	No	Yes	Yes
Scientific Communication	71	80	Yes	Yes	No	Yes	Yes
Basic Mathematics	86	75	Yes	Yes	Yes	Yes	No
Data Management	86	75	Yes	Yes	Yes	Yes	No
Maintenance	86	75	Yes	Yes	No	Yes	Yes
Safety	86	75	Yes	Yes	Yes	Yes	Yes
Technical Blueprints & Drawings	86	75	Yes	Yes	Yes	Yes	Yes
Critical Thinking	57	70	Yes	Yes	No	Yes	Yes
Probability & Statistics	57	70	Yes	Yes	Yes	Yes	Yes
Reading Comprehension	57	70	Yes	Yes	No	No	Yes
Automated Systems	71	65	Yes	No	Yes	Yes	Yes
Hydraulics	71	65	Yes	Yes	No	Yes	Yes
Lower-Level Mathematics	71	65	Yes	Yes	Yes	Yes	Yes
Machine Tools	71	65	Yes	Yes	Yes	No	Yes
Manual Machining	71	65	Yes	Yes	No	Yes	Yes
Manufacturing Materials	71	65	Yes	Yes	No	Yes	Yes
Manufacturing Processes	71	65	Yes	Yes	No	Yes	Yes
Pneumatics	71	65	Yes	Yes	No	Yes	Yes
Process Control	71	65	Yes	Yes	No	No	Yes
Quality	71	65	Yes	Yes	Yes	Yes	Yes
Robotics	71	65	Yes	Yes	Yes	Yes	Yes
Simulation	71	65	Yes	Yes	Yes	No	Yes
Basic Computer Skills	71	50	Yes	Yes	Yes	No	No
Basic Measurement	71	50	Yes	Yes	Yes	Yes	No
Hand Tools	71	50	Yes	Yes	No	Yes	No

D. Comparing Core Topics Across Levels

Table 7 compares the core topics across all three levels of curriculum. In general, there is extensive overlap since more advanced levels still build upon many of the topics in less advanced ones. The topics that are part of the core at all three levels tend to be industry-specific subjects that are either very comprehensive (e.g., safety, quality, manufacturing processes) or very basic (e.g., blueprint reading, basic measurement). Other industry-specific skills that are crucial components no matter the level include electronics, systems control, manual machining, and machine tools. The list also includes a number of human skills and general education skills such as lower-level mathematics, communication, critical thinking, reading comprehension, and professional skills.

However, the figure also makes it clear how each successive level adds unique topics that are not the focus of traditional Level 10 programs. In Level 20 programs, a focus on more advanced technical subjects starts to emerge, such as knowledge of instrumentation techniques and PLCs. In fact, level 20 programs appear to lay the groundwork for the connected manufacturing that is the focus of a subset of Level 30 programs, as evidenced by the prevalence of both mechatronics systems and robotics. Core technical skills such as troubleshooting and maintenance also appear here for the first time.

Finally, Level 30 programs suggest a more integrated and digitized approach to manufacturing, as evidenced by the importance of automated systems, as well as a number of digital skills such as basic computer skills, data management, and simulation. Fluid power systems have gained importance, as evidenced by the presence of both hydraulics and pneumatics. Finally, this level's focus on probability and statistics suggests that the ability to manipulate and interpret data is an important element of these programs, potentially in the context of production planning and decision-making roles.

There are a few apparent anomalies in the data, such as the fact that the topic of manufacturing materials appears in levels 10 and 30 but not level 20. This is a function of the academic programs and certifications in our database, as well as our analysis methodology. For this and other reasons, a purely unsupervised approach such as we used nearly always needs manual intervention to apply knowledge that is not embedded in the data itself. Therefore, as a next step, we plan to work with the MassBridge curriculum team, as well as industry and academic experts, to validate and enhance our initial analysis.

We recommend that the MassBridge curriculum include topics from levels 20 and 30. In our database, each topic is mapped back to existing programs, opening the possibility to re-use or adapt existing content rather than build it from scratch. Working with the curriculum team, we can converge on specific topics and content elements for the MassBridge program.

Table 7: Comparing the Levels (1 of 2)

	Core Topic		
	Level 10	Level 20	Level 30
Basic Measurement	Yes	Yes	Yes
Communication	Yes	Yes	Yes
Critical Thinking	Yes	Yes	Yes
Electronics	Yes	Yes	Yes
Lower-Level Mathematics	Yes	Yes	Yes
Machine Tools	Yes	Yes	Yes
Manual Machining	Yes	Yes	Yes
Manufacturing Processes	Yes	Yes	Yes
Problem-Solving	Yes	Yes	Yes
Professional Skills	Yes	Yes	Yes
Quality	Yes	Yes	Yes
Reading Comprehension	Yes	Yes	Yes
Safety	Yes	Yes	Yes
Systems Control	Yes	Yes	Yes
Technical Blueprints & Drawings	Yes	Yes	Yes
CAD/CAM	Yes	Yes	No
CNC Machining	Yes	Yes	No
GD&T	Yes	Yes	No
Manufacturing Systems	Yes	Yes	No
Research	Yes	Yes	No
Manufacturing Materials	Yes	No	Yes
Ethics	Yes	No	No
Statistical Process/Quality Control	Yes	No	No
Instrumentation & Sensors	No	Yes	Yes
Introductory Physics	No	Yes	Yes
Maintenance	No	Yes	Yes
PLCs	No	Yes	Yes
Robotics	No	Yes	Yes
Troubleshooting	No	Yes	Yes
Mechanical Elements & Power	No	Yes	No
Mechatronics Systems	No	Yes	No
Quality Control	No	Yes	No

Table 7: Comparing the Levels (2 of 2)

	Core Topic		
	Level 10	Level 20	Level 30
Automated Systems	No	No	Yes
Basic Computer Skills	No	No	Yes
Basic Mathematics	No	No	Yes
Data Management	No	No	Yes
Hand Tools	No	No	Yes
Hydraulics	No	No	Yes
Pneumatics	No	No	Yes
Probability & Statistics	No	No	Yes
Process Control	No	No	Yes
Scientific Communication	No	No	Yes
Simulation	No	No	Yes

VII. Developing and Launching the Curriculum

Developing a curriculum is never easy. Developing shared or standardized curriculum is even more difficult. Developing it in a domain as complex as advanced manufacturing adds even more difficulty. Manufacturing-related AA degrees in most schools have little room to add several new courses and competencies. Finding faculty willing to undertake the change or teach the new skills will also be challenging. And finding employers who want to hire the graduates, or sponsor work-learning collaborations adds difficulty.

Our interviews and other analyses identified four approaches that MassBridge could take to develop its curriculum. These include:

- Building or curating plug-in modules that schools can add to their existing programs,
- Creating a third-year advanced manufacturing technologist program
- Recreating the two-year technician program as an advanced manufacturing program from the ground up
- Focusing on years two and three of a three-year program

Because of the complexity of the challenge, MassBridge should consider what combination of the three approaches is best for Massachusetts, and the broader national context.

1. Building or curating plug-in-modules for existing two-year programs

A major barrier to adopting a new curricular approach is the effect on the existing curriculum. Having to replace or redesign existing courses is costly and requires attention that may be needed elsewhere. Recruiting faculty with new skills, or addressing inertia from faculty who do not want to change their approaches, can be daunting.

One way to address these challenges is to avoid them. Rather than changing curricula, MassBridge can provide modular content items that faculty can plug into their existing courses when they deem appropriate. Providing the modular content can help to speed adoption among those who are willing. MassBridge can use momentum and outcomes from early use of modular plug-ins to make the case for broader curricular changes. Useful plug-in content could include:

A. **Common labs and exercises** that teach critical thinking, blank-page skills in addition to other skills. Informants suggested that they could benefit greatly from access to lab exercises and teaching materials that go beyond the typical methods being used today. Labs could require students to manage ambiguity, make tradeoffs, or incrementally develop the information they need to achieve a goal.

B. **Industry-developed components.** Many programs already use industry-led course materials. For example, Amatrol is very common in manufacturing technician programs. It is an integral part of the IGNITE curriculum developed by LIFT, MxD, and America Makes in collaboration with other groups. DoD and others have funded other materials. For example, in the DoD-funded MEEP program, AIM Photonics, MIT Open Learning, Clemson University, and others are developing and testing VR modules to provide a more visual gamified approach to complex photonics education topics.

C. **Components from existing programs.** Several programs contained similar if not identical first and second year pathways. For example, manufacturing processes, print reading, college math, introductory physics, and systems are included in several of our exemplar programs. There are minor variations in what institutions define as college math, but these usually include algebra and trigonometry versus Calculus I and II. In addition, components exist from existing programs on digital production, Industry 4.0, and robotics. As other modules are developed for "further out" advanced manufacturing technologies (such as photonics, flexible electronics and biofabrication), the modules could be included here.

D. **Collaborative innovation exchanges**. Many teachers already have useful modules or techniques that others could use, if they knew about them. For-profit sites exist where teachers share lesson plans for virtually any topic. Academic conferences and publications provide best-practice sharing for those who attend conferences or have access to the materials. MassBridge could create a non-profit innovation exchange mechanism through which academic and industry instructors can share their best practices with others. This could include conferences, contests, a crowdsourced component library, or other mechanisms.

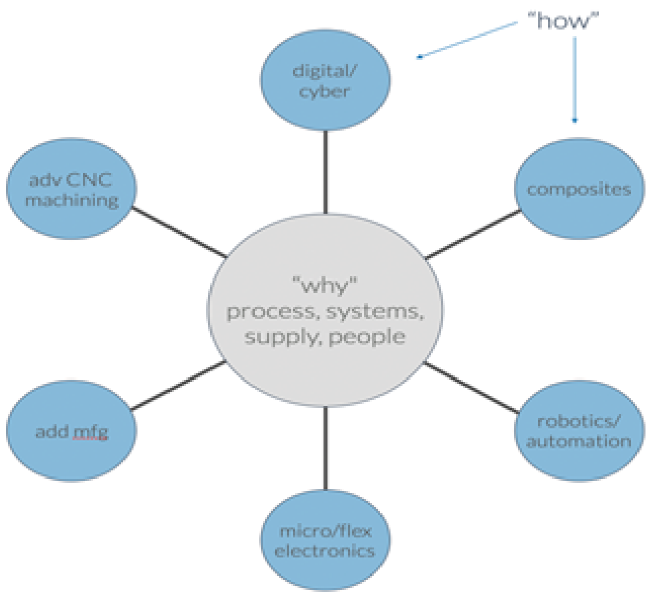
2. Creating a third-year advanced manufacturing technologist program

Current training for manufacturing technicians focuses students on mastering the specific "how" skills tied to particular existing technologies – such as how to operate a CNC milling machine or welding equipment. The students are trained to become tied to specific machines and fill narrow job categories such as machinist or welder. They know what to do and how to follow instructions, but know less about why processes work as they do, and how they fit into the larger production system. Troubleshooting systems or designing new processes are left to others who have training in design and engineering but often little experience in production roles.

There is a significant argument for a new kind of production worker, an advanced manufacturing "technologist" who can see beyond a specific machine to understand the operating system as a whole, and who can troubleshoot, make connections across a range of types of equipment, and adapt the system as necessary. NCATC defines technologists as a step beyond technicians – a "team leader" who "determines what can be improved in their industry and how to incorporate new technology, finds new ways to resolve problems, and further develops various processes." In survey after survey, manufacturing employers call for workers with "critical thinking" to manage the growing complexities of production. But that term has remained vague and undefined – it needs context.

One useful approach to meeting the technologist challenge is a hub-and-spoke model (Figure 4) being developed at MIT. The hub builds understanding of the "why" of (i) manufacturing *processes*, (ii) manufacturing *systems*, (iii) *supply chains*, and (iv) *people*. These elements give a student the bigger picture of how a factory floor, not just a machine, achieves optimal efficiency. Once students are introduced to these master hub competencies, they can be trained in technology-focused "spoke" skills in specific advanced manufacturing technologies and processes.

Figure 4: Hub and Spoke Model for Technologist Education



Source: John Liu, MIT Department of Mechanical Engineering (2020)

MIT's mechanical engineering department, after studying this need in industry, has developed versions of the hub program for both its manufacturing master's program and for a certificate "micromasters" program, now available online. To illustrate the demand that exists for these hub skills, there are currently more than 100,000 students enrolled in the micromasters program offered through MITx, MIT's online education system.[47] The revealed demand at the Master's level suggests significant latent demand at the Associate's degree level.

In addition to making advanced manufacturing modules that the state's community colleges and vocational technical high schools could insert into their programs, MassBridge could also organize a new technologist certificate program in its program offerings. This program could follow the hub-and-spoke model, training the growing middle ground between technicians operating their particular machines and engineers focused on engineering design.

Some schools have already adopted this technologist approach. As noted above, Lorain County Community College in Ohio has developed a technologist curriculum that leads to an applied bachelor degree. As a culminating degree, it is for applied, skill-based technologist training as opposed to an engineering degree or 2-year degree technician training. Wichita State University in Kansas, which is located in a major aerospace industry production center, has also developed a technologist program that builds additional skills on top of technologist training leading to an applied technology degree.

In a MassBridge program, critical thinking content about manufacturing systems, processes, supply chains and people would be central to the hub modules, while each spoke would address the knowledge of advanced manufacturing technologies with development assistance from particular manufacturing innovation institutes.

A technologist program doesn't have to be separate from the others – it could be integrated with the program, potentially in a modular way. Alternatively, the technologist program could be added as a third-year certificate after students have completed an associate or certificate program or the equivalent in technician training in existing manufacturing skills. Creating an additional certificate that could be stacked onto current technician training programs has the advantage of not forcing underlying technician training elements that a "technologist" will need out of the curriculum. Community colleges (or technical high schools and colleges) could adopt this hub-and-spoke curriculum, and they could offer a custom-curated set of spokes (or even lessons within a spoke) to address the in-demand skills for their regions. If their region's manufacturers need skills in digital manufacturing, additive manufacturing, and composite materials, for example, they could focus on those spokes as opposed to spokes on, say, flexible electronics. Longer term, through cooperation with the state college system, a bachelor's degree for applied manufacturing technologists could be considered and evolve.

3. Recreating the two-year program from the ground up

A very common concern that arose in our discussions of advanced manufacturing training is that there is no room to fit it into existing programs. Given the requirements and existing course designs in traditional programs, where would the new content fit?

In any system, whether educational, mechanical, or electronic, it can be very difficult to deliver significant new functionality by making the changes only within specific modules. Adding a new module can have limited effectiveness since existing modules and their interfaces can introduce costly overhead and sometimes conflicting signals. Major system-wide change often requires architectural innovation to redefine the modules and their interactions.

While most of our informants expressed concern about finding room for advanced manufacturing concepts among the courses already in their two-year programs, others had a different approach.

For example, Monroe Community College was able to transform part of its existing curriculum by lifting out legacy competencies that were created for an aging industry and adding back content that conformed to modern industry standards. Adaptability is pivotal in helping repurpose a curriculum in an efficient manner.

4. Focus on years two and three of a three-year program

It may be very difficult to train new students in everything they need for level 1-3 curriculum in only two years. However, students can learn many of the skills taught in the first year of a typical manufacturing program, such as engineering print reading, basic computer applications, and introductory math (algebra, geometry, trigonometry), prior to starting an advanced manufacturing program. Voc-tech high schools around the country have excellent training programs on basic manufacturing skills. Graduates of other high school programs may have the more academic skills such as math and physical sciences, and can learn the others through short courses from a variety of providers. Incumbent manufacturing workers already possess many of the introductory skills for manufacturing, but may need to supplement their academic skills.

If the goal is to produce students who are ready for advanced manufacturing occupations, it could be better for community colleges to focus their two years of courses -- and two years of financial aid eligibility -- on the unique courses that only they can provide. They could then work with local high schools and employers to ensure that entering students have the first-year skills needed to enter the two-year MassBridge advanced manufacturing program (which would focus on years 2 and 3 of a model three-year curriculum).

Students who apply to the program but are missing one or two skills can get advice on how to obtain them from online or other providers. Students who have a mix of prerequisites and those taught in the first year of the MassBridge curriculum (for example students with academic but not manufacturing basics, or incumbent workers who have the reverse) can be advised on how to shape their first year on campus so that they are fully ready to enter the second year along with all other MassBridge program students.

This would be a good program to build a work-based learning component into. This report has noted a number of programs that mix education programs with jobs in related manufacturing fields. It represents an optimal approach for workforce education. Projects with employers, coops or apprenticeships could well be included in this approach, as well as the other options, such as the technologist or "ground up" options.

5. Recommendations for the curriculum development process:

The four approaches described here – plug-ins for existing programs, third-year program, redesigned two-year program, or years two and three of a three year program – are not mutually exclusive; they are complementary. Each has its pros and cons. Modules in the basics of advanced manufacturing skills developed for program one can be snapped into the other three programs, for example. Redesigning the two year curriculum can allow community colleges to optimize teaching and lab hours to meet the needs of today's advanced manufacturing jobs, while eliminating overlaps and less-important topics that are the legacy of past generations for manufacturing training. However, it can be a difficult process requiring heavy investment in time from already-busy faculty and administrators. The use of plug-in modules could teach some additional skills within existing curriculum structures, but it will be dependent on the efforts of individual instructors, and it is unlikely to deliver all of the competencies required for advanced manufacturing, and will be missing much of the "why" content in the connecting and integrating skill set. A third year program is tempting because it creates curricular space to teach additional skills, but it requires an additional year of training for students, and will need extra work to ensure the programs are eligible for federal financial aid. The early-third-year approach can ensure that students arrive at the community college with basic skills, allowing faculty to focus on more advanced topics. But it makes the coordination challenge even more complex by adding high schools to the mix of parties that must agree on educational approaches.

We recommend that Massachusetts consider a combination of the approaches. The plug-in approach can create content that is useful for all of the approaches. It can also start to standardize some training across the Commonwealth's independent community colleges by providing modules and lab exercises that any instructor can adopt. At the same time, the Commonwealth can experiment with one or more of the other approaches depending on which schools and local employers are willing to experiment, and where the commonwealth can leverage existing programs and funding mechanisms.

Regardless of the approach(es) chosen, we recommend the following practices for curriculum development

A. Shift the curriculum development mindset from creation to curation

Given the immense amount of training material already available across the country, it is far better to curate a program rather than create it anew. MassBridge can borrow materials and approaches from some of the institutions described above. The industry and vendor leaders we interviewed were very willing to collaborate on designs. Certification agencies make their requirements and tests available to any organization, and will with schools and employers to create new ones. Some MUSAs have developed curricular elements, while others coordinate networks of groups that have relevant materials. To adopt the curation approach, it will be important to avoid a not-invented-here mentality. A combination of promoting existing examples and strategically creating time and resource constraints can help to foster a mindset of reuse rather than reinvention.

B. Foster methods to generate, and share, educational innovations across organizations

Although Massachusetts' decentralized management of community colleges can create coordination challenges, it can also be a tremendous source of innovation. Building on the mentality of curation rather than creation, encourage faculty and administrators to share their materials broadly, in return for recognition. Contests, conferences, and crowdsourced websites can all be ways to encourage innovation and sharing without requiring financial incentives to share. Massachusetts could also use existing or new coordination groups, such as MassTech or groups modeled on the Ohio Manufacturers Association and Ohio TechNet, to encourage creating and sharing materials. MassBridge could cast an even wider net, encouraging people from across the country, or even from advanced manufacturing economies such as Germany and Sweden to contribute materials.

C. Embed appropriate evaluation mechanisms, both for learning in each course and for work outcomes after graduation

For MassBridge to achieve its goals of state-wide and national adoption by schools and employers, it will need to show results. Most learning evaluations focus only at the course level, showing that students learned along the dimensions identified in the course's learning objectives. MassBridge should consider broader evaluation criteria, and embed them into the program as it is being built. Beyond course-specific measures, consider broader measures such as employment outcomes during and after the program, hands-on and problem solving skills rather than rote recall, flexibility to meet local needs, and outcomes for different demographics including for incumbent workers who may not take a whole program. These are more difficult to measure, and will require planning for pre- and post-measurement at the program level, and even with employers. The evaluation criteria should be developed in collaboration with faculty, administrators, employer groups, and possibly government agencies to ensure they meet the needs of all parties and that participating groups are willing to engage in their part of the process.

D. Tie to industry credentials

The content and quality of Associates degrees differ. Employers that know a school understand what its graduates can do. But what about the student who wants to work elsewhere? What about the student who moves to a new part of the country? Tieing academic training to industry certifications provides market transparency that is good for students and employers. In addition, the problem-solving and hands-on nature of many certification exams can motivate schools to make their curricula include these elements.

Furthermore, consider micro-credentials that provide evidence of skill attainment along the way. Two years is a long time for a community college student to wait for a better job. It is an even longer time for incumbent workers who must work, manage family concerns, and take classes. By linking courses to smaller certifications, or even to non-certified but locally recognized badges, schools enable workers to grow in their careers during the program, rather than hoping for a benefit at the end of the program.

VIII. Recommendations for Massachusetts and MassBridge

Massachusetts is an ideal context for the MassBridge project. The Commonwealth's skills cabinet fosters collaboration among the many agencies involved with workforce learning. The M2I2 program helps employers to invest in advanced manufacturing machinery, helping to increase demand for people who are skilled in those technologies. There is already successful experience working across boundaries between community colleges, vo-tech schools, and employers, and also across regions of the state.

Given this fertile soil, MassBridge will plant seeds that should grow into an extensive and successful program that can be a model for the rest of the nation. In the context of that metaphor, the examples and recommendations in this benchmarking report can be considered the water and nutrients that can help those seeds to grow.

Each section of this report provided useful practices and recommendations based on the analyses in that section. In this final section, we synthesize those recommendations and adapt them for the Massachusetts context. For more details on the recommendations, and the information behind them, please refer back to prior sections of the report.

Program content

Our analysis identified important elements of the advanced manufacturing curriculum, including specific skills and broader approaches to learning. In creating content for MassBridge, we recommend the following:

1. **Emphasize the why and how, not just the what.**

Our interviews and curriculum analysis indicate that moving from traditional manufacturing technician training to advanced training means more than just learning more advanced tools. It is a mindset change from direction-follower to systems thinker. Advanced manufacturing technicians (or technologists) should be expected to understand how the production machines work together, and why the production line works as it does. They must be comfortable with installing or adjusting machinery and troubleshooting production problems. They need to understand manufacturing as a system, including production processes, supply chains, and management. This mindset shift can be a challenge for technicians who have been trained for particular machines through traditional programs. MassBridge should find ways to build the more advanced mindset into courses throughout the program.

2. **Build a core for each level plus specialized options**

Our analysis identified an initial list of core curriculum components at the traditional, advanced, and connected levels of sophistication. All need to be more "applied learning" oriented and linked to problem-solving in real contexts. These lists can inform discussions and further analysis that leads to the final content list for the MassBridge curriculum. We recommend that the programs maintain a multi-level approach so that educators can easily understand how to tailor their existing programs for higher tiers of advanced manufacturing, and so employers can understand which modules may be most effective to help upskill their incumbent workers. Note, however, that the levels do not represent specific years of a curriculum. They represent tiers of concepts that educators can use to assure they are giving students the tools they need to succeed. These educators can then choose to use their own courses or to adopt modules from the MassBridge curriculum.

3. Include professional and other "human" skills

In addition to technical skills, employers value non-technical skills that are not typically taught in school. Numerous interviewees and programs refer to professional skills, such as showing up on time and collaborating well with colleagues and supervisors. However, advanced manufacturing requires additional skills such as critical thinking, problem solving, curiosity, and adaptability. One useful course could be the Human Skills Matrix[48], developed at MIT, which synthesized more than 40 different frameworks into a set of 24 key human skills. Another source is the Common Employability Skills from the National Network of Business and Industry Associations.[49] Consider incorporating skills such as these as complements to the technical training. Rather than offering classes in these skills, aim to build practice opportunities for these skills into the exercises and activities of each class.

4. Break down the work / learn barrier

In all of the programs described in this report, employers and education institutions collaborate closely on both content development and content delivery. Strong programs go beyond that to offer work components that range from internships to formal apprenticeships. We need earlier career / education guided pathways, not adding more time but replacing non-essential material with real-world, project-based learning modules that emphasize competencies not just traditional academic approaches. Adding a work component gives students an opportunity to integrate the skills they have learned in a real manufacturing environment, and develop professional skills they may not learn in the classroom. It also ties employers more closely to the academic program by allowing them to "try out" candidates before hiring them, and enabling employers to provide concrete advice on how to improve the educational program.

5. Tie to industry credentials and badges

Academic credentials alone can be a weak signal of skill, particularly if employers are not aware of a school's programs. Many employers increasingly want the assurance an industry-approved and accepted credential provides. The stronger programs we examined tie the learning not only to degrees but also to industry-recognized credentials. This approach does more than help graduates find jobs. It can help students finish their degrees. Earning a set of recognized credentials periodically during a program gives concrete feedback of the learning. It can also help the student grow in their careers even before they graduate.

6. Ensure that programs are eligible for financial aid

Short non-degree programs, and certificate programs that occur after graduation from a standard degree program, may not be eligible for federal student aid such as Pell Grants. The Education Department needs to improve the linkages between Pell and workforce education given the growing need. Meanwhile, since manufacturing training is often targeted toward young or lower-income students, it will be essential to ensure that MassBridge programs are eligible for this aid. Although federal guidelines can be difficult, many schools have been successful at structuring their innovative programs so that students can receive the aid that they need.

Curriculum design process

The complexity of the advanced manufacturing workforce context creates challenges for developing and deploying effective programs. To achieve success in the midst of numerous different and sometimes conflicting sets of actors and priorities, we recommend the following:

7. Consider multiple development approaches

We suggested four approaches to developing the MassBridge curriculum:

- Plug-in modules that schools can add to their existing programs,
- Third-year advanced manufacturing technologist program
- Two-year program redesigned from the ground up
- Years two and three of a three-year program that links to vocational technical high school or other programs

These options are not mutually exclusive and, in fact, can be complementary. Different institutions will be amenable to different approaches. We recommend beginning with plug-in modules to build momentum and experience. Then MassBridge can build on the experience to create other options for advanced manufacturing education.

8. Shift the mindset from creation to curation

Our research uncovered numerous exemplary programs ranging from traditional manufacturing to advanced technologies. The programs themselves, and the training systems they are embedded in, provide numerous examples that MassBridge can build upon rather than recreating. Starting from this mindset can help to build the core and to add optional advanced manufacturing content over time, likely in cooperation with the manufacturing institutes.

9. Embed appropriate evaluation mechanisms

MassBridge will achieve its goals of broad adoption only if it can show results. To do this, the program should build modules and programs with evaluation in mind. While course-level measures of student learning are useful, MassBridge should also plan for program-level measures such as employment outcomes or career growth. In the curation mindset, consider running "horse races" between different versions of a course or lesson to identify which version performs best. Clear measurement will help potential adopters see the value of the program and convince their colleagues to join.

10. Use modular approaches to deliver customized programs with standard quality.

"One size fits all" tends to fit nobody well. Employers want workers who are trained for the tools and technologies they use. But educational institutions have a strong incentive to use standard programs so they can deliver efficiently and at high quality. Building on the experience of IvyTech, which is described above, MassBridge can meet both needs. IvyTech schools teach a standard set of curricular modules, but can arrange them into different programs to meet the needs of specific regions, or even of specific employers. The custom programs meet market needs while the standardized component modules ensure quality.

MassBridge can take a similar approach. It can develop standard modules and model curricula in a number of advanced manufacturing technologies from which schools can choose. This modular approach can also enable the four curricular approaches, from plug-in modules to redesigned two or three year curriculum, described above. Schools can even build upon, or rebuild, modules to adjust them for specific technologies or software tools. In this way MassBridge can move from being a single set of courses to a library of modules that meet the needs of different schools and employers.

11. Build collaboration between the six pilot schools – and with employers

Massachusetts does not have a unified approach to curriculum statewide like Indiana does with IvyTech. Each school operates independently, designing its own programs to meet local needs, within certain statewide requirements. This independence can be an important source of value and innovation. However, it can increase the difficulty of coordinating the design and launch of a program like MassBridge that spans multiple schools. The challenge of decentralization extends to working with employers, which can express unique and sometimes conflicting requirements.

In general, community colleges should consider the "BILT" Model for engagement with businesses, which requires more active involvement with companies.[48] MassBridge can also build on the learning from two programs, described earlier, from the state of Ohio. The Ohio Tech Net program is a collaboration program and curriculum clearinghouse for all of the state's community colleges, through which school representatives meet biweekly to share best practices and new manufacturing curricula. Tech Net works closely with the Ohio Manufacturers Association (OMA) to ensure that programs meet the needs of employers and that employers can coordinate the requirements they present to educational institutions. Because technology will change and develop, manufacturing workforce education must be an ongoing process. MassBridge will need mechanisms to ensure state manufacturers and a working group of community colleges remain involved in advanced manufacturing education.

12. Ensure that the curriculum design works for underemployed and incumbent manufacturing workers in addition to new students

The advanced manufacturing skill gap can only be filled by a combination of training new students and upskilling existing workers. However, current workers, whether in manufacturing or other sectors, have different work and life contexts than new students. They come to the classroom with potentially valuable experience, but must balance their desire to upskill with many other personal and professional demands on their time. In building curriculum, ensure that the design enables incumbent workers to gain skills they need quickly in the context of a broader program of growth. Modular curricula and stackable credentials can allow incumbent workers to take specific courses as needed, while building to degrees over time. Adding options that recognize existing knowledge and experience can provide useful on-ramps into programs. Digital and hybrid programs can help workers to balance coursework with other demands on their time. In addition, schools can collaborate with employers, or groups of employers, to provide courses to cohorts of workers or to integrate learning more closely with the work environment. While many schools already incorporate some of these features into their programs, MassBridge should be intentional in ensuring that its programs work well for incumbent workers.

Scalability

Moving from pilot to statewide or national scale will entail another set of challenges. Scalability requires managing costs for schools, students, and employers. It also requires adapting the programs for the needs of different regions, and for an ever-evolving technology landscape. We recommend the following:

13. Better availability and use of equipment

Community colleges experience challenges in providing manufacturing students with enough hands-on time with up-to-date machinery. Currently available equipment may be non-standard, sometimes outdated or under-maintained. In other cases, it can be under-utilized because it is dedicated to specific programs and not shared.

States such as Connecticut have been successful at developing regional centers where students can access state of the art machinery supplied through funding from local employers and the state. This shared equipment is also available to high schools and programs that train incumbent workers. Massachusetts already has a model such as this at the Greater Lawrence Technical School and other state education institutions. The M2I2 program may be an avenue to partially fund the development of other such centers. Critical to the success of these centers will be using them for multiple groups of learners, as happens in Lawrence, so that the equipment is utilized to the fullest extent possible.

14. Use technology to maximize the value of limited hands-on time

Software tools and online platforms can be an effective way to scale the productivity of capacity-limited hands-on labs. For example, not all of the hands-on time in a lab is productive. Students need to learn the basics of safety or of each machine's controls before they can begin making products. They also make mistakes that can slow the learning for others, increase costs, or even take equipment offline. Simulators such as Amatrol's Skill Boss are relatively inexpensive ways to teach students the basics before they touch an expensive machine tool. Newer approaches using AR or VR, including programs being developed at MIT, can help students come up to speed without hardware simulators. These projects are also developing augmented reality methods to give students guidance while they are at the machine, making their experience more productive and allowing teachers to focus on higher-order learning with the students.

15. Scale up the upskilling

Massachusetts manufacturers are already having trouble finding manufacturing workers. With an aging manufacturing workforce these problems will only get worse. In addition to demand-side programs to increase participant interest in manufacturing jobs, manufacturing educational programs will need to grow in size and content breadth to meet workforce needs for the new advanced manufacturing skills. As importantly, incumbent manufacturing workers will need upskilling to keep up with new technologies. The state's plans to share vocational technical high school manufacturing facilities with students from traditional high schools, as well as trainees from workforce development boards, is one such effort. In addition, online modules and software tools can help schools manage increased education loads, as noted above. A significant number of community colleges in other parts of the country are already devoting much of their manufacturing workforce development programs to customized credit, non-credit and contract training for employers' upskilling needs. Our community colleges will also need to develop more incumbent worker upskilling programs with area manufacturers. If the state's community colleges can show they have mastered advanced manufacturing education through MassBridge, this should help interest manufacturers in such programs. Linking schools to incumbent workers at manufacturing firms creates a virtuous cycle. By working collaboratively to understand and serve the manufacturers' needs, schools can create more demand for their graduates and even closer linkages to the manufacturers.

16. Energize a community for content development and delivery

MassBridge can create an excellent curriculum, but it will always be limited by the knowledge and resources available to the team. Rather than seek to create or curate a single curriculum, consider MassBridge as a library of materials that can grow over time. Enable local schools to customize MassBridge modules for their specific contexts. Foster programs to encourage sharing curricular innovations, not only across Massachusetts, but nationwide. Conduct conferences and contests through which educators can share their ideas and receive broad recognition for their contributions. By energizing a community around the goals of MassBridge, seeding the conversations with useful components, and encouraging sharing across schools, MassBridge can serve many diverse educational contexts without having to invest in building curricula for each one.

IX. Conclusions

It is important to understand, up front, that the success of a new workforce training program for advanced manufacturing skills will only succeed if the state's manufacturing firms are adopting new advanced manufacturing technologies. Firms, particularly SMEs, are reluctant to train skills for new equipment they don't yet have. Therefore, workforce training efforts must proceed in parallel with advanced technology implementation efforts, including Massachusetts' unique M2I2 program to assist firms and research institutions in acquiring advanced manufacturing capital equipment.

Concerning content delivery, consortia of industry and educational institutions appear key. These can be industry-led or education-led, although the latter offers cost savings options to employers as long as they are closely aligned to the industry-specific skills companies need. Benchmarking of these approaches has identified a series of best practices detailed above that MassBridge can consider in its planning. As Massachusetts has understood by implementing MassBridge, states can play a significant role in scaling up advanced manufacturing education. A review of relevant efforts in multiple states identified some approaches that MassBridge can consider.

Overall, development and dissemination of advanced manufacturing content requires use of existing curricula where available for closer-in manufacturing technologies and new curricula for further-out technologies. For both, the manufacturing innovation institutes may be able to play a constructive role in support of the MassBridge project. DoD ManTech's pending online platform to collect and disseminate advanced manufacturing online content could be a useful resource.

We suggested four potential approaches to developing curriculum, including plug-in modules, a third-year "technologist" program, a newly designed two-year program, or focusing on years two and three of a three year program. These approaches need not be exclusive, and can build on each other. Providing a set of options may aid in the adoption of MassBridge by educational institutions operating in different contexts across the state or the country. In addition, industry-recognized, transportable credentials should be embedded into advanced manufacturing curricula to enhance the value of academic programs to both employers and students. These have not yet been developed for many areas of advanced manufacturing, although manufacturing institutes may be able to play a role in their development.

To summarize, the MassBridge advanced manufacturing education content could be implemented through improved delivery systems discussed above, with employer or educational-led collaborations helping to develop and broadcast the new content, adopting a series of new best practices to do so.

APPENDIX A: List of Programs Included in the Database

Curriculum Level	Type	Focus Area	Institution	Title
10	**Associate**		Chippewa Valley Technical College	AAS Mfg Eng. Technologist
			Ivy Tech Community College	AAS Industrial Tech. (Industrial Electrical Pathway)
				AAS Industrial Tech. (Industrial Mechanical Pathway)
				AAS Industrial Tech. (Process Operations Pathway)
				AAS Machine Tool Tech. (CNC Production Machinist Pathway)
				AAS Machine Tool Tech. (Machine Tool Pathway)
				AAS Mfg Production and Operations
			Lorain County Community College	AAS Mfg Engineering Tech. - Computer Aided Machining
				AAS Mfg Engineering Tech. - Industrial Electrical Technician
				AAS Mfg Engineering Tech. - Industrial Mechanical Technician
				AAS Mfg Engineering Tech. - Mechanical Design
			Monroe Community College	AAS Applied Integrated Tech. (Precision Machining Track)
				AAS Mechanical Tech.
			Wichita State University Tech	AAS Machining Tech.
	Certs./Comp. Models		MACWIC	Applied Mfg Technology Pathway
			MSSC	Production Technician
			NOCTI	Mfg Technology
			SME	Mfg Technologist
20	**Associate**		Bristol Community College	AAS Adv. & Biomedical Mfg Tech.
			Cape Cod Community College	AAS Eng. Tech. & Adv. Mfg (Civil or Mechanical Eng. Pathway)
				AAS Eng. Tech. & Adv. Mfg (Electrical Eng. Pathway)
			Community College of Rhode Island	AAS Adv. Mfg Tech.
			Des Moines Area Community College	AAS Adv. Mfg Tech.
			Gateway Technical College	AAS Adv. Mfg Tech.
	High School		LIFT	Ignite Adv. Mfg Technician
	Associate		Manchester Community College NH	AAS Adv. Mfg Tech.
			Monroe Community College	AAS Applied Integrated Tech.
				AAS Applied Integrated Tech. (Optical Fabrication Track)
				AAS Applied Integrated Tech. (Precision Machining Track)
			Northern Essex Community College	AS Eng. Science Adv. Mfg Electronics Concentration
				AS Eng. Science Adv. Mfg Precision Machining Concentration
			Quinsigamond Community College	AAS Mfg Tech.
			Wichita State University Tech	AAS Industrial Automation and Machine Maintenance
	Certs./Comp. Models		AMTEC	Adv. Mfg Modules
			DoL ETA and SME/CFAM/MI/SMI	Adv. Mfg Comp. Model
			Urban Institute	Competency-Based Occupation Framework Industrial Maintenance Mechanic

APPENDIX A: List of Programs Included in the Database (continued)

Curriculum Level	Type	Focus Area	Institution	Title
30	Associate	Industry 4.0	Lorain County Community College	AAS Mfg Engineering Tech. - Industrial Internet of Things
		Robotics	Ivy Tech Community College	AAS Adv. Automation and Robotics Tech.
				AAS Industrial Tech. (Automation and Robotics Pathway)
			Wichita State University Tech	AAS Robotics
	Certs./Comp. Models	Additive Manufacturing	ToolingU/SME	Additive Mfg
			Urban Institute	Competency-Based Occupation Framework Additive Mfg Tech
		Industry 4.0	Festo	Industry 4.0 Certification
			NIMS	I4.0 Smart Maintenance Specialist
				I4.0 Smart Process Specialist
				I4.0 Smart Production Specialist
				I4.0 Smart Systems Integration Specialist
			SACA	Certified Industry 4.0 Automation Systems Specialist Certifications
				Certified Industry 4.0 Production Systems Specialist Certifications
		Mechatronics	DoL ETA and PMMI	Mechatronics Comp. Model
			Siemens	Mechatronic Systems Level 1
				Mechatronic Systems Level 2
				Mechatronic Systems Level 3
			Urban Institute	Competency-Based Occupation Framework Mechatronics Technician/ Engineer
		Photonics	ETA-I	Photonics Technician Operator
				Photonics Technician Specialist
				Specialist Precision Optics
				Technician Precision Optics
		Robotics	NOCTI/FANUC	Robot Operator 1
				Robot Operator 2
			Urban Institute	Competency-Based Occupation Framework Robotics Technician

APPENDIX B: Methodology for Identifying Core Curriculum Attributes

1. <u>Methodology for Finding a Core at Each Level</u>

Once each course and competency was tagged with the appropriate topics, we could use this information to identify the "**core**" list of topics that characterize programs at each "advancedness" level of manufacturing. Indeed, determining which topics were consistently present across the programs within a level allows us to approximate the subjects and skills required to succeed within that career. To describe the methodology for pulling out the core at each level of manufacturing, we'll walk through how we determined the core for Level 20 (Advanced Manufacturing Technician):

We first restricted the database to Level 20 programs (both academic degrees and certifications/competency models). Then, for each of the ~145 topics:

- We count the number of Level 20 programs that address this topic at least once.
- We compute the percentage of academic degrees that address this topic at least once and the percentage of certifications/competency models that address this topic at least once.

To account for the imbalanced number of academic degrees and certification / competency models, we then use two methods to identify the most prevalent topics across Level 20 programs:

- First, top topics are identified by highest percentage overall: these are the 20 topics that are addressed by the greatest percentage of Level 20 programs, regardless of type. (Note: because of ties, there may actually be more than 20 topics.)

- Second, top topics are identified by highest average percentage: these are the 20 topics that are addressed by the highest average percentage across Level 20 program types. Specifically, this percentage is computed by averaging the percentage of certifications/competency models and the percentage of academic curricula that address a topic to give equal weight to both types of programs. (Note: because of ties, there may actually be more than 20 topics.)

The list of top topics by count and top topics by percentage are then combined to create a "core" list of topics for this level. There tends to be much overlap between the two lists, resulting in a maximum of 30 core topics at each level.

This process is repeated for the other levels until we have a "Core" for each level that should capture both industry demands and academic approach for that segment of manufacturing.

2. Methodology for Finding a Core at Each Level: Example Table

	# of L20 Programs with this Topic			% of L20 Programs with this Topic			L20 Top Topic		
Topic	Certs.	Academic Degrees	Total Percentage	Certs.	Academic Degrees	Average Percentage	By Total Percentage	By Average Percentage	Overall Core
Total	**3**	**15**							
Safety	3	11	**78**	100	73	**87**	Yes	Yes	Yes
Technical Blueprints & Drawings	3	11	**78**	100	73	**87**	Yes	Yes	Yes
Communication	2	15	**94**	67	100	**83**	Yes	Yes	Yes
Quality	3	10	**72**	100	67	**83**	Yes	Yes	Yes
Electronics	3	9	**67**	100	60	**80**	Yes	Yes	Yes
Machine Tools	3	9	**67**	100	60	**80**	Yes	Yes	Yes
Manufacturing Systems	3	9	**67**	100	60	**80**	Yes	Yes	Yes
Instrumentation & Sensors	3	8	**61**	100	53	**77**	Yes	Yes	Yes
Basic Measurement	3	7	**56**	100	47	**73**	Yes	Yes	Yes
Maintenance	3	7	**56**	100	47	**73**	Yes	Yes	Yes
PLCs	3	7	**56**	100	47	**73**	Yes	Yes	Yes
Systems Control	3	7	**56**	100	47	**73**	Yes	Yes	Yes
Troubleshooting	3	7	**56**	100	47	**73**	Yes	Yes	Yes
CNC Machining	2	11	**72**	67	73	**70**	Yes	Yes	Yes
GD&T	2	10	**67**	67	67	**67**	Yes	Yes	Yes
Manual Machining	2	10	**67**	67	67	**67**	Yes	Yes	Yes
Manufacturing Processes	2	10	**67**	67	67	**67**	Yes	Yes	Yes
Robotics	2	10	**67**	67	67	**67**	Yes	Yes	Yes
Mechanical Elements & Power	3	5	**44**	100	33	**67**	No	Yes	Yes
Mechatronics Systems	3	5	**44**	100	33	**67**	No	Yes	Yes
Introductory Physics	2	9	**61**	67	60	**63**	Yes	No	Yes
Professional Skills	2	8	**56**	67	53	**60**	Yes	No	Yes
CAD/CAM	1	12	**72**	33	80	**57**	Yes	No	Yes
Critical Thinking	1	12	**72**	33	80	**57**	Yes	No	Yes
Lower-Level Mathematics	1	12	**72**	33	80	**57**	Yes	No	Yes
Research	1	12	**72**	33	80	**57**	Yes	No	Yes
Problem-Solving	1	9	**56**	33	60	**47**	Yes	No	Yes
Quality Control	1	9	**56**	33	60	**47**	Yes	No	Yes
Reading Comprehension	1	9	**56**	33	60	**47**	Yes	No	Yes
Basic Computer Skills	3	4	**39**	100	27	**63**	No	No	No
Hand Tools	3	4	**39**	100	27	**63**	No	No	No

3. Defining a Program

Note that a crucial part of this process is defining what counts as a single program since the program unit determines how often a topic can be counted as well as the topic percentage values. There were two definitional issues here:

- Pathways: many of the associate degrees we included in the database contain a number of pathway options that often result in substantially different curriculum requirements. For example, the Ivy Tech Associate Degree in Industrial Technology contains six pathways that each differ by as much as 27 credits out of a total 60: 1) Automation and Robotics, 2) Welding, 3) Process Operations, 4) Quality Assurance, 5) Industrial Mechanical and 6) Industrial Electrical.

  Counting the entire family of curricula under the AAS in Industrial Technology as a single program would set unreasonable expectations with regard to the number of topics that can be addressed by a single degree. However, recognizing each pathway as its own curriculum may bias the top topic results towards the list of topics addressed in the 33 credits that each of the pathways has in common since these will now be counted six times.

  As a compromise, each pathway was considered its own program (containing both the 33 common credits and the 27 unique credits). However, we dropped some of the pathways from our analysis if they were not as relevant to the focus of creating an advanced manufacturing degree. For example, in the case of Ivy Tech, the Quality Assurance and Welding pathways were omitted from the analysis.

- Level 30 Programs: Level 30 programs are by definition concerned with different, sometimes highly specialized branches of advanced manufacturing. The purpose of including this level in the analysis is to see whether patterns can be identified across these branches, despite them dealing with different content. If a topic spans multiple branches, that is a pretty good indication that it would be relevant to an Advanced Manufacturing degree.

  However, the different branches of manufacturing are not equally represented across existing academic degrees and Certs/Comps/competency models. On the educational side, we found a number of degrees in Robotics, one degree with an Industry 4.0 focus, but nothing for the other four Institute branches.[3] On the certification/competency model side, we were able to find a number of Robotics programs (by NOCTI / FANUC and the

[3] We also found one degree in Additive Manufacturing, but because this program was not offered by an institution that was recommended to us or local to Massachusetts, it is not currently in our database.

Urban Institute), two Additive Manufacturing programs, a number of Photonics programs (all offered by ETA-I), three Mechatronics programs, and a number of Industry 4.0 programs (from Festo, NIMS, and SACA). However, we found nothing for the three remaining Institute branches.

The uneven coverage of Level 30 branches poses a challenge because the top Level 30 topics will inevitably be biased towards the branches with the most programs. To combat this bias, we created a “Focus Area” variable for the Level 30 programs and considered all the programs falling within this a single focus area to count as a single program. While this approach erases variation in content across different credentialing institutions, it gets at the central questions of identifying the core topics across branches.

APPENDIX C: List of Topics in the Curriculum Analysis

Topic	Higher Level Topic
Accounting	
Additive Manufacturing	
Advanced Machining	
Advanced Tooling	
Algorithms	
AR & VR	Assistance Systems
Automated Systems	
Basic Academic Skills	
Basic Computer Skills	
Basic Mathematics	
Basic Measurement	
Business	
CAD/CAM	
Calculus & Pre-Calculus	
Chemical Engineering	
Chemistry	
Cloud	
Communication	
Computer Engineering	
Computer Programming	
Computer Systems	
Connected Systems	
Continuous Improvement	Production Performance
Critical Thinking	
Customer Focus	
Cybersecurity	
Data Analysis	
Data Management	
Databases	
Design for Manufacturability	
Digital Electronics	Electronics
Digital Logic	
Digital Thread	Cyber-Physical Systems

APPENDIX C: List of Topics in the Curriculum Analysis (Continued)

Topic	Higher Level Topic
Electrical Control	
Electrical Drives & Power	
Electrical Engineering	
Electrical Fabrication	
Electrical Wiring	
Energy	
Enterprise Resource Planning	Production Planning
Environment	
Ethics	
Facility Planning & Design	
Fiber Optics	
Finance	
Fluid Basics	
Fluid Power	
GD&T	
Hand Tools	
Hazardous Materials	
HCI & HMI	
Human Factors & Ergonomics	
Hydraulics	
Information Systems	
Instrumentation & Sensors	
Internet of Things	Cyber-Physical Systems
Introductory Physics	
Inventory	
IP	
Lasers	
Lathes & CNC Lathes	CNC Machining or Manual Machining
Lean Production	Production Performance
Legal	
Logistics	
Lower-Level Mathematics	
Lubrication	
Machine Tools	
Management	

APPENDIX C: List of Topics in the Curriculum Analysis (Continued)

Topic	Higher Level Topic
Manufacturing Cells	
Manufacturing Fundamentals	
Manufacturing Graphics	
Manufacturing Materials	
Manufacturing Processes	
Manufacturing Systems	
Marketing	
Material Handling	
Materials Science	
Mathematical Analysis	
Mechanical Design	
Mechanical Elements & Power	
Mechanical Engineering	
Mechanical Systems	
Mechatronics Systems	
Mills & CNC Mills	CNC Machining or Manual Machining
ML & AI	
Molding	
Nanotechnology	
Networks	
Object Recognition	
Operations	
Optics	
Photonics	
PLCs	Systems Control
Pneumatics	
Power Plant Systems	
Precision Measurement	
Predictive Maintenance	Maintenance
Preventative Maintenance	Maintenance
Principles of Engineering	
Probability & Statistics	
Problem-Solving	
Process Control	Systems Control

APPENDIX C: List of Topics in the Curriculum Analysis (Continued)

Topic	Higher Level Topic
Process Design	
Process Planning	
Product Design	
Professional Skills	
Project	
Project Management	
Prototyping	
Psychology	
Quality Control	Quality
Reading Comprehension	
Research	
Reverse Engineering	
Robot Programming	Robotics
Robotics	
Robotics Design	Robotics
Safety	
Science	
Scientific Communication	
Simulation	
Soft Skills	
Software Development	
Solid Mechanics	
Statics	
Statistical Process/Quality Control	Quality
Supply Chain	
Systems Design	
Systems Thinking	
Technical Blueprints & Drawings	
Thermo & Kinetics	
Tooling	
Troubleshooting	
User Interface	
Welding	
Work Experience	

Notes on Tagging Methodology

As indicated by the tables above, the list of topics is characterized by a hierarchy. If the right column, “Higher Level Topics,” is not empty, then every time a class or competency is tagged with the topic in the left column, “Topic,” it will also be tagged with the topic in the right column. For example, every class and competency that is tagged with Robot Programming is also tagged with Robotics. This setup reflects the fact that Robot Programming is a subset of Robotics, but may be too advanced or niche to rise to the top of the core lists on its own.

Importantly, the relationship between the two columns is not reciprocal. That is, a class or competency can be tagged with a “higher-level” topic without being tagged with a corresponding “lower-level” topic. This setup reflects the fact that many course or competency descriptions are not descriptive enough to be tagged with anything more specific than what is indicated by the higher level topic.

APPENDIX D: Selected Interview Summaries

In this appendix we provide short summaries of selected interviews. As additional interviewees approve their summaries for publication, we will make them available. Note that these short summaries reflect only excerpts of what was discussed in each interview.

FANUC / NOCTI

Our team spoke with FANUC and NOCTI about advanced manufacturing skills and curricula. NOCTI provides nationally validated industry standards in several occupational clusters. They establish credentials that are linked to those standards, and award those credentials based on industry expected competence. They provide credentials related to advanced manufacturing in areas like electronics, power distribution, manufacturing technology and CAD-CAM.

FANUC defines advanced manufacturing as the integration of technologies working together. That is, foundational equipment and process control along with the data analytics all working in concert. They mentioned one barrier is finding a way to get education to move at the speed of business.

The skills needed, at a technical level, are infinitely more digital than even ten years ago. The older skills learned on the job are still relevant, but new employees are entering the workforce needing to learn those skills, as well as new technologies. Today's employees need to know how an entire system works, regardless of their own position.

Another concern is the difficulty in attracting students to this field since there's been a stigma on manufacturing. FANUC looked at surveys and found that the number one influencer for students had to do with experiences. We need to think about how we can put a real robot in a student's hand. That will help them see why they are taking applied math and other classes that will become essential in jobs of the future.

Students now have a broad range of interests in jobs, and rarely is it in manufacturing, from coding to fashion and sports. Manufacturers have found success telling students that they could be working with the big influencers in all of those fields. Nike, L'Oréal and other big companies are all using robotics and need new manufacturing specialists. If we can't take them to these facilities we can at least show them via virtual tours and social media outreach.

FANUC has a stackable set of certifications, in three levels. They are: Operator level 1 (Book tested), Operator level 2 (hands on evaluation by a trained expert and set review), and Technician level 3 (fully hands on assessment - integrated with Rockwell Automation). Level 3 is a system skill set with Fanuc and Rockwell combined which teaches how to troubleshoot systems and the need to understand the whole system.

NOCTI has been working with America Makes to develop a certification assessment. They are beginning to deliver micro-credentials for their own content as well. They'd like to have assessments in junior high that might help place certain students on a career path in advanced manufacturing. They suggested MIT look at competencies and how they cross over in building a new curriculum. They have developed and delivered all of the certification assessments for FANUC but FANUC develops their own curriculum.

Festo

Festo is a global leader in automation technology, and the world market leader in technical training and education. They help with development of curricula, educational programs, and certification, training outsourcing for industrial companies as well as consulting and evaluation of competence development programs. Their curricula development focuses on curricula for vocations, developed according to the national qualification framework. They have modular structures and integrate dual elements of theoretical knowledge and practical exercises.

They have a three tiered model of completion: (1) Fundamentals, (2) Advanced Mechatronics, and (3) Industry 4.0. The industry 4.0 certification was created in collaboration with NC3 in response to demand from industry leaders with support and curriculum development from Festo.

Festo offers an apprenticeship program as well. Retention rates with the apprenticeship after five years is very high (nearly 85 percent). The curriculum is created to prepare workers to think and solve problems. They have added emphasis on critical thinking and soft skills.

Industry 4.0 is evolving so fast that there might not be another industrial revolution, technology and education will stay on a never-ending trajectory keeping momentum with technology and students up to date on processes that will matter in the new economy.

Gateway Technical Community College (Wisconsin)

Gateway Technical College began in 1911 as America's first publicly funded technical college, preparing students to achieve their academic and professional goals. Their hands-on training in over 70 programs of study prepares 21,000 students annually to enter new careers or advance their current ones.

Gateway has completely revised its curriculum to coincide with the Foxconn project. Foxconn played a role in educating Gateway about the role of big data, data analytics, automation and robotics in the production process.

When creating the new curriculum they started by asking "What does the new advanced manufacturing landscape look like?" From there they developed two basic paths to find academic talent to recruit into a modern manufacturing technician job. Unfortunately, they found it hard to break the stereotype of manufacturing to enroll that talent. The southeast Wisconsin area knows manufacturing, but not the new manufacturing landscape. As they developed their curriculum, they saw the need to include high schools as well. Students were coming into Gateway without the proper math skills needed to be successful in that curriculum. They really stressed the importance of collaborating with high schools to make sure students on the path to a technical community college were where they needed to be before getting to the associates level.

As they were building their new curriculum, they held an online symposium for all community colleges in WI for a full year. Even now, they continue to meet quarterly to discuss changes in advanced manufacturing and ways the curriculum can be improved or updated.

FANUC and Rockwell have been helpful as well. They helped Gateway create ways to teach data analytics, predictive maintenance, and the school was able to leverage Fanuc and Rockwell materials on robotics and controls.

Gateway also mentioned that finding qualified instructors is challenging. They usually hire experts from within the industry who have little to no teaching experience, noting that classroom professional development is also very important.

Curriculum of note:

Term	Course #	Cr.	Course Title	Requisites (prereq- before/ coreq-with)	I-E
1	890-155	1	Gateway to Success (G2S)		F+
1	*664-110	2	Intro to Mechatronics		F
1	*664-100	2	Intro to Industrial Control Systems		F
1	*605-113	3	DC/AC I[2]		F
1	804-115	5	College Technical Math 1[1,2]	Prereq: 834-110	F+
2	*664-105	2	Intro to Industrial Robots		S
2	*664-115	2	Interpreting Engineering Drawings		S
2	801-136	3	English Composition 1[1,2]	Prereq: 831-103 OR 831-107	S+
2	*605-114	3	DC/AC II[2]	Prereq: 605-113; Coreq: 804-115	S
2	*605-130	4	Digital Electronics[2]	Coreq: 605-114	S
3	*605-136	3	PLC System Design	Prereq: 605-130	SU
3	*664-102	3	Motor Controls for Advanced Manufacturing	Prereq: 664-100; Coreq: 801-136	SU
3	809-195	3	Economics[1,4]	Prereq: 838-105 OR 831-107	SU+
3	*664-120	2	Intro to Industrial Internet of Things (IIot)		SU
3	801-198	3	Speech		SU+
4	*606-160	3	Fluid Power and Design		F
4	*664-117	2	Materials and Processes	Prereq: 664-100; 664-110; 801-136	F
4	*664-111	3	Machine Mechanisms	Prereq: 664-100; 664-110; 804-115	F
4	*664-116	2	Intro to Mfg Quality Control Systems	Prereq: 664-115	F
4	*664-121	2	Vision and Smart Sensors	Prereq: 605-130; 664-102	F
5	*664-112	3	Fundamentals of Machining Processes		S
5	*664-122	2	Engineering Project Management	Prereq: 801-136	S
5	*664-101	2	PLC Industrial Control System Applications	Prereq: 605-136; 664-102	S
5	*606-138	2	Design Problems	Prereq: Instructor Consent; 801-136	S
5	809-198	3	Psychology, Introduction to[1,2,4]	Prereq: 838-105 OR 831-107	S+

Competencies of note:

- ➢ Gain hands-on experience with tools and equipment you'll use in the field as you operate and program robotics, troubleshoot computer networks and interface digital logic circuits.
- ➢ Cutting-edge training labs will expose you to the latest technology and precision instruments so that you have the confidence to succeed in any professional environment.
- ➢ Prepare for Industry 4.0. Gateway has fine-tuned this hands-on training to make you a top choice for career opportunities at Foxconn. Completing this Preferred Program does not guarantee employment.

Ivy Technical Community College System (Indiana)

Ivy Tech has career focused programs in Healthcare, IT, Business and Advanced Manufacturing. The Advanced Manufacturing degrees provide a well-rounded plan of study that prepares students for a broad range of technical positions within business and manufacturing. They offer elective focus areas in: manufacturing design, production technology, mechatronics, digital and systems integration, mechanical, electrical, and manufacturing operations. Ivy Tech has also used modules from the IGNITE curriculum, developed by LIFT and two other manufacturing institutes.

Ivy Tech has a three-tier system that builds toward their advanced manufacturing degree, Advanced Automation and Robotics Technology AAS, in 75 hours (typically five full-time semesters). The core of the program starts with manufacturing 101 and 102 which aligns with basic manufacturing processes, safety, quality, and maintenance awareness to prepare students for the Certified Production Technician (CPT) which is required by some of the manufacturing industries in their region. The certification stacks to a certificate (CT) at 18 credit hours adding subjects including PLC's, design work and computer aided design. The next level is Technical Certificate (TC) at 30 credit hours in automation and robotics (in partnership with, for example, Cummins). The 75 hour program includes relevant parts of the 60 hour program with a stronger emphasis on mechatronics.

Ivy Tech is Indiana's community college system. It is the largest post-secondary institution in Indiana and the largest community college in the country. It is one college, singly accredited with over 40 locations across the state. They have one curriculum that is verified and unified by the state. Assignments and resources are universal which helps make classes identical regardless of the location you take the courses. They have 22 campuses with a manufacturing program and labs. Each program on each campus has a curriculum advisory board which advises the program ensuring the curriculum is aligned with the needs of the employers in the campus service area. They meet at least twice a year to upgrade curriculum and suggest new courses and competencies if needed for employable students. Faculty from each campus service area meet together at least two times per year to compare input from the advisory boards and develop and redevelop curriculum.

Most of the curriculum is set; however, each course can be modified up to 30% - customized by faculty to tailor to their region's network of employer partners. Special topics courses can also be developed and used as electives when needed.

Ivy Tech also leverages certifications by building them into the core curriculum. This helps with setting desired competencies. Certificates also give students flexibility to start and stop on their own time and schedule, or for returning students to quickly earn a new competency while on the job. They have set up intentional on and off ramps to support the way their demographic progresses in their careers.

As mentioned, Ivy Tech listens to their industry leaders and considers both the students and industry leaders their customer. They've heard employers requesting more education in system integrations, sensors, data analytics, and autonomous vehicles. Of course implementation is not instantaneous; it may take up to a year or more to integrate some of the skills needed to compete for jobs. As a result of the input from industry, the college is implementing a new degree to focus on competencies for current and future careers, Smart Manufacturing and Digital Integration (SMDI). It should be available in fall 2021.

Having strong and progressive leadership at the school also helps, they are evolving nearly every semester and still are not able to keep up with advances in technology. Schools must connect with the community and industry partners to ease this burden. Students and employers need to have confidence in their education and know that they are creating the most up to date curriculum to meet their needs. Ivy Tech also hosts summits for employers to give feedback on graduates, competencies, and new technologies.

One member commented that having come from a manufacturing background herself she knows that "Just because you can design it, doesn't mean you can build it." What she's seen is that automation is helping free up workers for more innovation and critical thinking.

Curriculum of note:

See completion guide.

Competencies of note:

- ➢ Design, program and troubleshoot programs for computers, PLC's, robots and other industrial software.
- ➢ Utilize electrical/mechanical troubleshooting and communication skills to diagnose, repair, test, and return to service failed components.

- ➢ Describe the hazards associated with automated machines and determine appropriate safety methods for working around computer controlled machinery.
- ➢ Teamwork – Function effectively as a member of a technical team.
- ➢ Identify and Solve Problems – Identify, analyze, and solve narrowly defined technical problems.
- ➢ Communication – Apply written, oral and graphical communication skill in both technical and non-technical environments; identify and use appropriate tech literature.
- ➢ Lifelong learning – Understand the need for , and engagement in, self-directed continuing professional development
- ➢ Professional/Ethical/Diversity – Demonstrate understanding of and commitment to address professional and ethical responsibilities, including a respect for diversity.
- ➢ Quality, Continuous Improvement – Demonstrate a commitment to quality, timeliness, and continuous improvement.

Manchester Community College (New Hampshire)

Manchester Community College (MCC) and its collaboration of seven community colleges in the New Hampshire region believes that each program should have a focus. MCC's focus is automation technicians - and more specifically mechatronics. Their goal is helping students enter the workforce in a specific area in one or two years.

One reason for distinct pathways at each school is efficiency, they realized early that buying the same high-tech equipment for neighboring schools didn't make sense, and that economically it was nearly impossible. Having seven schools working on seven different pathways has changed the landscape in New Hampshire community colleges. Each school has independent control of their curriculum but each reports to the same board for approval.

Because everything is much more customized, manufacturing has become a completely different industry than what it was even ten years ago. MCC teaches students how to work with engineers which is important so they know how to eventually think like engineers. A large part of that is teaching students how to become problem solvers and how to think beyond the original question - critical thinking is essential.

One problem they've seen through extensive collaboration with regional industry is that most students will finish a one-year program and be hired immediately, they rarely return for their associates degree. There is high demand for these students and many are leaving school with a one-year degree and making more than double their salary before entering the program. A cycle develops where those technicians within a year or two become managers and new roles open for technicians. MCC is having trouble filling open positions at the current rate of need.

MCC stressed the importance of having an advisory board of industry partners. Theirs includes: DEKA, Hitchiner, GE, Spraying Systems, Stonyfield, and other small and large manufacturers.

Hitchiner specifically has been involved from the inception of the MCC robotics program. They use the one year robotics certificate as a benchmark for their highest class and paid robotics technician. Their program is about more than just learning a skill; it's about learning how to be valuable employees: being on time, being part of a team, and being adaptive learners. The classes in the program are heavily project based.

The one year program does not include on the job training for credit, but they partner with local vendors who do internships and they have a strong apprenticeship model in place in the state. They hope to eventually expand this program to the high school level as well.

MCC prepares the students for the workforce and allows local manufacturers the opportunity to complete the detailed day-to-day work on the job. For advanced manufacturing education to evolve schools need to stop putting students into silos and start giving them a small taste of what's available in industry. They should let the students find their career path. Further, many graduates of MCC were disenchanted when moving up to the four year degree pathway at UNH because the equipment wasn't as new or they had theory fatigue.

Another aspect of MCC's curriculum is teaching students how to learn. Many of their students come to MCC with a completely different mindset to what learning in the classroom really entails. They provide much of the curriculum online where students can learn theory on their own or through video and an enhanced online learning system. The students must then complete in-person hands-on training which is more project based.

Core competencies include quality control, safety, and professionalism. MCC professors consider themselves more than teachers, they are mentors preparing students to enter the workforce. They also have a great success rate with females in manufacturing in their program. Their female participation is higher than most with a 15 percent enrollment rate (general average is 5 percent).

To date, the biggest challenge facing MCC is funding. Their materials budget is only $15K/year. The main issue is writing grant proposals for new equipment to keep up with industry. They found that by the time the funding came the new equipment may have become obsolete.

MCC belongs to the Florida Advanced Technological Center (FLATE), they are also partnering with other schools around New England to increase awareness in mechatronics programs.

Curriculum of note:
Year one
Manufacturing Processes
Introduction to Engineering Design and Solid Modeling
Engineering Print Reading
Electrical Fundamentals for Manufacturing
College Algebra with Trigonometry
MCC Essentials
Motor Controls and PLCs for Manufacturing
Basic Machining Practices
Pre-Calculus
College Physics
College Composition I with Corequisite or College Composition I
Year two
Manufacturing Systems I
Material Science
ROBO210M for Robotics Pathway, ADMT230M for Mechatronics Pathway
College Physics II
Foreign Language/Humanities/Fine Arts Elective
Manufacturing Systems II
ROBO211M for Robotics Pathway, ADMT225M for Mechatronics Pathway
Open Elective
Social Science Elective

Competencies of note:

- Implement and control automated manufacturing processes
- Design components and assemblies using Solidworks
- Use 3D printers, laser cutters, and CNC equipment to fabricate prototypes
- Illustrate flow of materials and resources within the manufacturing cycle
- Control a manufacturing system to create finished product
- Program material handling robots and equipment
- Perform system analysis and master the troubleshooting process
- Master lean manufacturing process to maximize production of a product
- Have theoretical knowledge and hands-on practice in electronics, mechanics, computer systems and software control systems

MassHire

MassHire creates and sustains powerful connections between businesses and job seekers through a statewide network of employment professionals. Their twenty-nine MassHire Career Centers connect jobseekers and businesses for employment opportunities, and their sixteen MassHire Workforce Boards engage business in building long-term talent solutions across the Commonwealth.

The MassHire State Workforce Board (MSWB) advises the Governor on building a strong workforce development system aligned with state education policies, and economic development goals. Beginning in 2010 they were approached by the Western MA Chapter of the Tooling and Machining Association, a consortium of small and medium sized enterprises hoping to build relationships with local community colleges and vocational high schools. Over the past decade they have worked together with manufacturing companies to build and market training programs.

Building sustainable relationships with educational institutions/training providers will ensure that the curriculum to be taught is aligned with their technical needs and requirements, and will allow the companies the opportunity to create the strategic initiatives that will help them. Many of the small and medium size enterprises that make up the advanced manufacturing ecosystem across Massachusetts are time strapped and need assistance, guidance, and resources to build and sustain true industry-education partnerships that are committed to "partnering for solutions".

Most manufacturing companies understand the value-add of a "technologically relevant" incumbent workforce and support their employees in their efforts to access after-shift training opportunities that accommodate their work and life cycles. Many of the available training/upskilling opportunities occur in the early evening time period and require the employees to attend classes that can take the employee away from their family during family time. This has become another obstacle to upskilling incumbent workers.

Advanced manufacturing companies across Massachusetts continue to develop innovative practices to attract and retain a more qualified and motivated workforce. Small and medium sized manufacturers are critical to the future of work and engaging them in a meaningful way should be a major end-game objective of the MassBridge initiative.

Most of the vocational technical high schools in Massachusetts offer a manufacturing training program but also conduct a wide range of career focused technical programs, including but not limited to HVAC, healthcare, electronics and carpentry that are of significant interest to the students.

The MassHire state-wide network could play a major role as an "intermediary" that brings together schools and companies to ensure that the development and execution of the Level 3 technical curriculum is aligned with the technological needs and requirements of the Manufacturing USA Institutes going forward.

Monroe Community College (NY)

One advantage for Monroe Community College (MCC) is their new training center which will be opened in spring 2022. This will allow them to not only expand on their Mechatronics programming which includes training for mechanical and electrical, but create new programming to meet the multifaceted skillsets with industry 4.0 technologies – for example cloud, IT, analytics, big data, automation, concepts for PLCs, sensors, and robotics. The new training center will be in MCC's downtown campus on two floors, spanning 50,000 sq. ft. of lab and classroom space.

Their curriculum integrates electrical, mechanical, and computer controls so that students are prepared to work in the operations, installation, and maintenance of automated and robotically controlled systems and manufacturing technologies. Upon completion of the program graduates would be qualified for jobs in industrial maintenance and manufacturing including assembly, testing, startup, troubleshooting, repair, and upgrades of machinery and the associated control systems.

Curriculum of note:

FIRST SEMESTER
Technical Mathematics I OR College Algebra OR higher*
System Electricity
Introduction to Programmable Logic Controller
Mechanical Systems
Hydraulics and Pneumatics
SECOND SEMESTER
College Composition OR Advanced Composition
Technical Mathematics II OR Statistics I AND MTH 164 - Introduction to Trigonometry OR System Control Electronics
Advanced Programmable Logic Controllers
Computer Applications for Technicians
THIRD SEMESTER
Technical Writing
Technical Graphics OR Computer Aided Drafting/Design - Solid Modeling
Technology and Values***
Applied Physics I OR PHY 145 College Physics I
Dimensional Metrology
FOURTH SEMESTER
General Internship
Engineering Materials
Mechatronics Systems
Introduction to Sociology

Core competencies of note:

- ➢ Develop a personalized troubleshooting process to diagnose and repair system failures.
- ➢ Explain how a system operates by reading and interpreting electrical, pneumatic and hydraulic schematics.
- ➢ Understand the role of an intelligent computer system, such as Programmable Logic Controllers, to monitor and control the production process.
- ➢ Work within a team environment to maintain production equipment.
- ➢ Demonstrate proper use of diagnostic tools to identify and verify system malfunctions
- ➢ Perform both preventive maintenance and corrective maintenance procedures.

NIMS Credentials

NIMS credentials are earned by students, trainees, apprentices, employees, and military personnel nationwide and around the world. Their credentials meet the industry established standards. Their credentials list can be found here.

NIMS defines advanced manufacturing as Industry 4.0 saying it's all about CNC, automation, and robotics. In past years companies were roughly 80 percent manual equipment, now nearly all manufacturers have CNCs. They have noticed a changeover happening which is basically the Intersection of new technology and the internet and computing (Internet of Things).

They are launching a national ad campaign to improve manufacturing attractiveness - the effort will be led by large corporations and ACCC. They have postponed the launch due to COVID but it should launch in the near future. They have also been working to have community colleges align courses to standards and credentials developed by NIMs for certain companies, collaborating with industry and education.

They described Haas Automation as an exemplar, a company that has systematically invested in US education by offering scholarships and cost reduced equipment for schools - particularly in areas with jobs promoting the use of Haas equipment. They have their own certification program of online courses that are designed to provide the basic knowledge necessary to get started as a CNC machine operator or CNC machinist. They offer an introduction to basic CNC machine operation, proper machine safety, and fundamental machining processes.

Using its industry expertise, NIMS has applied concepts of modularity and adaptability in training and performance validation to develop a new Smart Training Framework that is revolutionizing the process to help companies and educators meet the growing demands for qualified and certified industrial workers. Its customizable format is aligned with manufacturers on the smart manufacturing journey and it is created with job roles, not occupations, using three main components:

1. **Industry Standards (Smart Standards).** Highly customized and all standardized enable proper training for employees in a world where technology emerges and changes faster than an average individual can master in their career span. They reveal job roles and adapt to ever-changing technology and workforce requirements.

2. **Smart Training Principles.** Universal and timeless constants that ensure the highest quality in all training and reveal true performance validation. These Smart Training Principles empower organizations to develop highly customized training programs that meet their needs and stabilize quality of training with clear return-on-investment. Gone are the days of conformance to a one-size-fits-all training and workforce development model.

3. **Smart Performance Measures.** In order to properly define, validate, and benchmark employee performance, the Smart Performance Measure framework provides the communication mechanisms needed among all stakeholders in an employer's stakeholder community: Organizations, Trainers, and Trainees. They measure performance of each stakeholder and reveal end performance, which provides clarity, transparency, and unification of the applied learning.

NIM is now using its Smart Training Framework for credential development and they have offered to share it more in depth with our group. The new jobs go beyond running the machine. They include troubleshooting and critical thinking, more soft skills and less manual or physical labor. NIMS tests for some of these soft skills during hands-on performance evaluations. They also add problems throughout their courses that demonstrate whether or not the student is thinking critically to solve advanced problems. Finally, they suggested that the cost of equipment in schools is another key barrier to educating the future workforce. Without funding from the government, the cost is very prohibitive.

Peerless Precision (MA)

Peerless Precision is dedicated to helping their customers get parts on-time and done right. They have developed a Machined Part Design for Manufacturing Guide to help product developers design parts with the manufacturing process in-mind for better efficiency.

There are a few core competencies Peerless looks for when hiring including: must be vocationally trained, have an ability to read and understand blueprints, 'shop math' including geometry and trigonometry, quality inspection techniques, and understanding basic measurement equipment. They must also be able to apply those skills on the job. They value soft skills or professionalism, for example coming to work on time and putting in extra effort to advance their career and continue learning. Their employees need to know manual machining and how to prepare a machine for every single job, but they also need to know troubleshooting and preventative maintenance.

There is always push back when a new technology is introduced but Peerless sees it as a chance for improvement. Students who are exposed to new technologies will bring suggestions about better ways to use them in the future. SME needs more hands on training programs, they don't have the people who can teach and who know the technology.

One of the main issues now for the industry and for educating the future workforce is recruitment. They've had a difficult time finding the right workers and finding career workers who might make good teachers. Many workers would have to leave industry, get a teaching certificate, and then begin teaching which is not efficient and can be economically prohibitive.

In May, Peerless will participate in a virtual career fair to bring awareness to students about advanced manufacturing jobs and education. The event entitled CHARGE UP YOUR FUTURE: The AMPED MFG Career Summit, aims to bring students, parents and teachers into an interactive Virtual World to discover careers in manufacturing. The event is designed for anyone searching for a high-tech, high-growth career.

Peerless is working with schools and credential providers to find the right programs or degrees that will train employees fast without overloading them with classes they may not need in their work. They currently work with Springfield Community College (MA) and Asnuntuck Community College (CT) for internships and other opportunities for Peerless to collaborate with education leaders in and around their community.

Peerless mentioned that a similar program to the Ohio Manufacturing Association (OMA) could work in MA. They are currently a member of the Western Mass Chapter of the National Tooling and Machining Association (WMNTMA), but they haven't seen the level of coordination that OMA seems to produce. They suggested talking to other industry leaders in MA including Steve Tamasi (Boston Centerless) and Mike Tamasi (AccuRounds), Steve Capashaw (VSS-Greenfield), and Eric Hagopian (Pilot Precision Products), who in particular is a champion for worker education.

RAMTEC

RAMTEC partners with manufacturing industries to provide training, training sites and facilities, and high school programs throughout Ohio. The state of Ohio is focused on working with students to update skills. Students have a pathway from high school to a four year apprenticeship, then start working for a local manufacturer (Whirlpool for example). RAMTEC works with several organizations to create that pathway from the classroom to industry. They are working with schools around the country to find ways to fit the needs of industry leaders.

One large focus is at the instructor level. Most instructors aren't coming from industry, so training the instructors can be just as important as the curriculum itself. RAMTEC works to keep their instructors up to date and make sure the Industry 4.0 delivery model is as up to date as technology. One issue they've had is that industry poaches their teachers - to offset this they have created a "train the trainers" model - a way to reach hundreds of instructors across the country.

RAMTEC now has in Ohio 24 training sites, 38 instructors, 192 credentials requested, 746 training stations, and over $11M in equipment. They have a 2 year curriculum program for colleges in robotics, the programs are for 26 to 40 credit hours at Marion Technical College where they have a long working relationship.

List of partners: FANUC, Rockwell Allen-Bradley, Yaskawa, Universal Robotics, US Congressional Robotics Caucus, Parker, Mitsubishi, Siemens, OSHA, FANUC CNC, OSHA, NCATC, ARM, RIA, SME PRIME, PLTW, and various colleges throughout Ohio.

Curriculum of note:

First Semester:

Intro to Engineering
Introduction to Electricity
Intro to Programmable Controllers
Robotics I
Engineering Drawings and Diagrams
Applied Technical Math
Computer Applications

Second Semester:

Circuit Analysis I
Mechanical Drives
Fluid Power
Applied Physics
College Algebra

Third Semester:

Circuit Analysis II
Advanced Programmable Controllers
Robotics II
English Composition I
Statics
Sociology
Career Readiness

Fourth Semester:
Analog Electronics
Automated Process Control
Oral Communication
Ethnic and Cultural Diversity
Eng Coop Work Exp

Core competencies:

- ➢ Read, interpret and modify engineering drawings, diagrams and schematics used in manufacturing and production environments
- ➢ Design, interpret, analyze and troubleshoot analog circuits for both DC and AC applications
- ➢ Interpret and analyze and troubleshoot digital electronics
- ➢ Demonstrate the ability to effectively use appropriate tools and instruments to analyze and troubleshoot electrical and mechanical systems and equipment
- ➢ Integrate, program, operate and troubleshoot industrial robots used in manufacturing and production environments
- ➢ Interface, program, maintain and troubleshoot automation systems based on programmable logic controllers
- ➢ Design, analyze and troubleshoot mechanical and electrical diagrams for the installation and repair of control systems including valves, motors and sensors
- ➢ Demonstrate adherence to safety when working with energized or physical hazards in a manufacturing and production environments

Rockwell Automation

Rockwell collaborates with universities and non-profits to shape and offer classes, labs, hands-on learning, and events that prepare students for the sophisticated technologies employed in industry. They foster diverse thinking and help prepare students for careers that evolve with technology.

They mentioned their FIRST® initiative, a mentor-based program that engages students from kindergarten through high school as a model for manufacturing awareness. They encourage employees to volunteer as mentors, judges, and referees as FIRST events.

Rockwell is looking for workers who have higher skills including problem solving, data analytics, and critical thinking skills. They have been working in high schools, vocational schools, community colleges and four year institutes to find ways to minimize the risk associated with hiring talent.

Rockwell defines advanced manufacturing as a way of taking manufacturing that isn't connected and connecting it, analysing it, and optimizing it to make the transfer from design phase into the manufacturing phase quicker. The result is greater productivity and flexibility. A fully connected system has a multi-plant connection which creates the new connection in manufacturing that describes industry 4.0. Integrated disciplines are crucial to this, for example, automation and robotics need to work in concert.

In a multi-vendor environment Rockwell insists they need to have workers who have studied various subjects and are able to connect things that haven't been designed to be connected. They have started developing a curriculum that can bridge the gap between what community colleges offer and their employees with a four year degree.

Rockwell often forms collaborations with schools, and in doing so, they work with local industries to determine the learning needs in specific regions. They then look at these connected systems and collaborations and can establish what skills need to be increased in each region. They often target a higher than average salary for work in the field based on stronger credentials, the salary is competitive at roughly $30/hour or $65,000 a year.

Soft skills are another important aspect to finding the right workers. They categorize these skills into a professional education level including: being on time, writing well, being organized, and communicating well as part of a team. They also suggested and shared with us the Gateway Tech curriculum for advanced manufacturing.

Rockwell's collaboration with learning institutions includes:

- ➢ Educational visits to RA sites
- ➢ Thought leadership / guest lecturers and participation on advisory boards
- ➢ Co-investment and access to products
- ➢ Industry credentialing and recognized certifications
- ➢ Internships, placements, and early career pathways

Finally, Rockwell suggested three areas in learning which can adapt the most:

- ➢ Industry value and relevance of existing curriculum and teaching methods
- ➢ Integration of disciplines and collaboration across faculty silos and new approaches to academic administration
- ➢ Responsiveness in learning institutions is significantly slower than the industry page of technology adaptation.

Engineering and Science Technologies Career Pathway

Secondary Pathway: **Engineering and Design** Postsecondary Program: **Engineering Technology**

An Example of Courses with Secondary and Postsecondary Credits

Secondary	7 8	English I	Algebra I	Physical Science	Social Studies	Fine Arts	Pre-Engineering Technologies		
	9 10	English II	Algebra II	Biology	World History	Health (.5) PE (.5)	Engineering Principles	Engineering Design	World Languages
	11	English III	Geometry	Chemistry	U.S. History	Manufacturing Operations	Digital Electronics	World Languages	
	12	English IV	Trigonometry/ Calculus	Physics	U.S. Government	Robotics	Alternative Energy		
Postsecondary	Year 1 1st Semester	English Composition I	Technical Math I	Intro to Engineering	Manufacturing Processes	Engineering Design			
	Year 1 2nd Semester	English Composition II	Technical Math II	Physics I	CAD I	Hydraulics & Pneumatics	Statics		
	Year 2 1st Semester	Chemistry	Strength of Materials	Physics II	CAD II	Ethics			
	Year 2 2nd Semester	Group Communication	Mechanical design Project	Engineering Economics & Organization	Programmable Logic Control	Robotics	Alternative Energy		

High School Career-Technical Education Program Courses

High School Courses for Postsecondary Credit (Including Apprenticeship Hours) and the Corresponding Postsecondary Courses

Required Courses

Recommended Electives

Visit education.ohio.gov/CareerConnections for reference information.
Course titles and sequences will vary between schools.
4/2015

Level 3: Robotics Integrator

Advanced Product ID	HMI	Advanced Robotics	Advanced PLC	Smart Maintenance	Cyber Security
Vision Technology II Near Field Communications RFID II Potential & Impact	Manufacturing Processes Programming Creating Visual Awareness Recipe Creation Data Acquisition	Collaborative Robots Augmented Reality IRA Safety Standards Integration of PLC's w/Robotics Virtual Commission	Sensors III OPCUA w/MES & PLC I/O Condition Monitoring Advanced Networking & Connectivity	Predictive Maintenance Data Analysis LEAN & Visual Awareness Top Floor- Shop Floor Communication	Data Corruption: Understanding Risks & Consequences Preventing Cyber Attacks

Level 2: Robotics Specialist

Product ID Fundamentals	Applied Fluid Power	Applied Mechanical Systems	Applied PLC	Applied Robotics	Applied Industry 4.0
Vision Technology 1 RFID 1 Bar Coding 1	Maintenance & Troubleshooting Energy Efficiency Vacuum Technology	Gear Drives Bearings & Gaskets, Seals Clutches & Brakes Ball Screws and Linear Bearings	Sensors II PLC Technology II Basic Networking CoDeSys	Programming & Editing Maintenance & PM Welding Material Handling Palletizing	Introduction to MES Introduction to HMI Introduction to Data Safety Introduction to 3D Modeling

Level 1: Robotics Technician

Electricity Fundamentals	Fluid Power Fundamentals	Mechanical Systems	PLC Fundamentals	Robotics Fundamentals	Industry 4.0 Fundamentals
Electricity AC Electricity DC	Basic Hydraulics Basic Pneumatics	Mechanical Drive Systems Components & Calculations Belts, Chains, & Lubrication Maintenance & Installation of components	Sensors I PLC Technology 1	Introduction to Robotics	Introduction to Industry 4.0

Siemens (Mechatronic Certification Program)

Siemens offers a certification program that can be inserted into current associate's degree programs or as a standalone program for continuing learners. More information on the Siemens Mechatronic Systems Certification Program (SMSCP) can be found here.

Their approach to building the curriculum was to look at a four-year engineer level education and then simplify it for a technician student level. That helped them define skills. It also led to the three tiered system of education presented in the program: (1) Certified Mechatronic Systems Assistant, (2) Certified Mechatronic Systems Associate, (3) Certified Mechatronic Systems Professional. Soft skills are not a major focus — troubleshooting, systems understanding, and the ability to understand complex systems using a diagnostic approach, a problems approach is their goal.

They have had success with tailoring jobs to specific industry pipelines. For example, a partner school in Georgia feeds students directly into Hyundai and Kia plants in the area. They also work extensively with high schools in Michigan and South Carolina for example, introducing students to advanced manufacturing in high school which leads them to the community college curriculum at neighboring institutions and eventually into the workforce.

Curriculum of note:
Course 1: Process Control Technologies
Course 2: Introduction to Totally Integrated Automation (TIA)
Course 3: Automation Systems
Course 4: Motor Control
Course 5: Mechanics and Machine Elements Course 6: Manufacturing Processes

Core competencies:

- ➢ Understand and analyze the technical specification of mechatronic systems, subsystems, modules, and components
- ➢ Derive and determine parameters for mechatronic systems and system elements
- ➢ Measure, interpret, and analyze electrical, PLC/microcontroller, and mechanical values
- ➢ Assemble and install tools and hardware systems
- ➢ Perform scheduled and preventive maintenance
- ➢ Install, implement and modify software tools used in mechatronic systems
- ➢ Use troubleshooting skills to identify, foresee, and prevent possible problems, conflicts, and failures, and to systematically and intelligently make repairs
- ➢ Program mechatronic modules and systems, especially PLCs
- ➢ Implement PLC networks, including configuration and data transfer using bus systems
- ➢ Analyze system logs

- Incorporate relevant technical literature into understanding of system operation and use this information to propose procedural and operational changes
- Observe and incorporate safety standards
- Apply knowledge of process control technology, including all regulator types
- Observe, follow, and influence cost control and process efficiency procedures
- Execute all of the above as an effective member of a team

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