# A Need for Digital Enterprise Workforce Development


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***ABSTRACT***
*As model-based definition (MBD) becomes prevalent throughout the enterprise, the need to educate both new hires entering the workforce and those who author and consume traditional product definition is critical. A tactical education and training plan is essential to the success of MBD adoption. Workforce development for MBD adoption within an enterprise requires three phases: 1) Establishing literacy 2) Building practitioners 3) Establishing mastery. As an organization moves its people through these phases of awareness, competency, and mastery, not only are training programs required but a strong communication ramp-up is also needed to bolster the enterprise knowledge. Challenges in current practice will be highlighted as they relate to establishing a successful MBE workforce.*


**A Future State of Digital Manufacturing**

According to numerous studies [1, 2, 3] somewhere around 2025, the typical U.S. worker will have around 20% of the information they need to do their job created and delivered to them by a machine, likely some type of computer with some form of artificial intelligence (AI). Near that same time period, the world will experience over 35 billion things connected to the Internet. Living in such a connected world will no doubt have an influence on how people work, as well as how they are prepared for such work. A very good example of this playing out before our eyes today is in the U.S. manufacturing sector.

According to many of those same studies, the U.S. will have likely experienced the creation of roughly 3 million manufacturing jobs that do not exist today by 2025, and will still have roughly 2 million unfilled jobs that have been digitally transformed to require a new skill set. This scenario will create even more strain on an already burdened labor market in manufacturing [4,5]. When the strain on the existing workforce is coupled with new models of working, such as a borderless workforce and non-hierarchical organizations, and the design and manufacture of wearable products and continuously connected, intelligent devices, and one can see that an entirely new ecosystem of work is developing. One for which our current education systems and methods have but minimal preparation. Current life expectancies in developed countries point to a person born today living to be nearly one hundred years old. How do we educate a person born today to exist in a world where they not only change jobs multiple times, but potentially change *careers* multiple times as technology advances? Demand for skills of the head (cognitive), have dominated those of the hands (technical) and to a lesser extent, those of the heart (social) over the past 300 years. In the future, those skills shifts are about to go into reverse. During the first three Industrial Revolutions, the skills workers needed to keep ahead of the machines were largely cognitive. Machines were doing manual tasks and cognitive tasks were the exclusive domain of humans. However, with the rise of social networks, AI, and the digitalization of information, Industry 4.0 threatens to change the balance of power in what had been exclusively the human's cognitive domain.

By most accounts these days, the manufacturing sector in the U.S. is doing well, even with the recent downturn in the automotive vertical. However, it is difficult to pick up a newspaper without reading something in it about the challenge companies are facing when trying to fill their open jobs in manufacturing [6]. According to numerous recent studies by the likes of Gartner, Deloitte, McKinsey and others, the current manufacturing output is high, but the future looks a bit bleak. Not necessarily due to competition with low-labor cost countries or due to some governmental policy per se, but to a lack of a skilled workforce coupled with rapid technological change. When reading the contemporary literature about these phenomena, most authors peg the shortage between three million and six million manufacturing workers by 2027. Regardless of the cause, even if it is "fixed", it will not likely address a more fundamental trend in the U.S. that has been ongoing for many years – people choosing other career fields over manufacturing. But before diving into a discussion about education and workforce development, let's look briefly at the technological transformation at the heart of this predicament in which we find ourselves.

Most of us grew up learning about *the* Industrial Revolution – the *mechanization* of work to ease the load on human beings and to increase their efficiency. However, what many people may not be aware of is we have had several industrial revolutions over the last two hundred years. Industry 1.0 began with the mechanization of work, which led to the *electrification* of work during Industry 2.0 in the late 1800s and early 1900s. In the early 1960s, electrification of work gave way to the *automation* of work with the rise of personal and industrial computing to create Industry 3.0. And as those technologies became commonplace and we saw the use of data begin to increase, we have arrived in the 2010s to Industry 4.0 – the *digitalization* of information to support the intelligent automation, and computing backbones that have been built. Not only are we on our fourth industrial revolution, but the elapsed time between the revolutions has been substantially decreasing, somewhat analogous to Moore's Law and the clock speed of computing over the years. It gets faster and faster in shorter periods of time.

In parallel to the technological gains in efficiency, accuracy, and sustainability that the manufacturing sector finds itself experiencing today, it is struggling to transform its workforce. For every industrial revolution the world has seen, there has been an accompanying educational revolution. In the U.S. and Europe, those transformations came in the movement away from the master/apprentice model (Education 1.0) to the movement around Manual Arts and Industrial Arts (Education 2.0), which focused on basic job skills for the growing mass production economy. Over the 20$^{th}$ century, we saw the move towards Technology Education, with its focus on domain-specific content areas and a systemic view of technology as a discipline in and of itself (Education 3.0). The current education transformation relative to manufacturing is now focused on design thinking and a 'system of systems' view (Education 4.0) of developing and implementing technology, and using digital data to assess, diagnose, and implement solutions to problems.

Yet, if we have had parallel revolutions between industry and education, why does the manufacturing sector find itself with such a shortage of skilled workers, and how might we begin to address this shortage? The remainder of this article will focus on those questions, and while there are certainly issues such as politics, global economics, family and social dynamics, and personal preferences at play here, those are not specifically within the scope of the current discussion at hand. The current discussion will primarily be focused on how we can adapt our Education 4.0 revolution to better address the needs of the manufacturing sector of our economy.

The dawning of technologies such as AI means that humans will no longer have the cognitive playing field completely to themselves. Machines will be able to process more quickly, more cheaply and with fewer errors than their human counterpart, at least in some activities. While this could lead to the hollowing-out of human tasks, now cognitive as well as manual, at a far greater rate than ever before, it could also present future opportunity for jobs that relate to the designing, developing, and maintaining of intelligent systems [7]. So what do humans have left? What should we prepare our students and evolving workforce for? Students must be exposed to and become proficient in multiple modes of problem solving; cognitive tasks requiring creativity and intuition to solve tasks or problems whose solutions require great logical leaps of imagination. There will remain a demand for skills to program, test and oversee machines. Personalized design and manufacturing will become more common as the information needed to customize products for individuals is more readily available. A student's ability to use their social skills to execute, and when necessary, lead tasks that require emotional intelligence rather than cognitive alone. Preparing graduates solely for cognitive skills will not be enough for the 4th Industrial Revolution.

**Educating the Workforce**

We must build upon the traditional literacies of reading, writing and mathematics [8,9]. Students must still be able to take in information, assimilate it with what they already know, and form a conclusion. They must still be able to understand the physical and temporal phenomena expressed by modern mathematics and science. However, we must move them past simply assimilating and synthesizing information and towards interpretation and systematic decision making based on that information synthesis. New types of literacy might include:

- **Data literacy**: the ability to read, analyze and apply information. Advanced data gathering and analytics tools will seek to act on the user's behalf when presenting highly visual information. It will be incumbent on our students to know how to *apply* that information to their problem.
- **Technological literacy:** coding and engineering principles. Technologies have been created and used since the beginning of human kind, which is arguably one of the things that separates humans from their ancestors. Yet the new incarnation of technological literacy will be one that sees our students able to incorporate intelligence into their physical tools and objects they design and build.
- **Human literacy**: humanities, communication and design. Our ability and willingness to connect to fellow human beings through, and in spite of, our technologies will become increasingly important. Solving complex problems will not only need the rational theorems and postulates of our mathematical techniques, but the empathy that comes from being human, as we have yet to develop a computing technology with the human capacity to assimilate, interpret, and *feel*.

Not only do we need to develop in our students these higher-order literacies based on digital tools and information and higher-order *mindsets* and ways of thinking about and viewing the world, we must also do that within the incumbent (existing) workforce. We must encourage them to embrace systems thinking; not necessarily the abstract mathematical representations of it, but the

Gestaltist [11] view that yields the ability to view an enterprise, machine or subject *holistically*, making connections between different functions in an integrative way. The manufacturing sector will not have the luxury of displacing or replacing all of its existing employees. Manufacturing employees must also become culturally agile, as physical and geographic borders become increasingly irrelevant in an age of global commerce and the economic viability of singular customers, and supply networks become increasingly complex. To accommodate such a transformation in the manufacturing paradigm, a product and process information set must be sufficiently sophisticated, encompassing not only explicit definition and meaning, but implicit and semantic details as well. Doing this will require the creation of digital product and process definitions that are built on sound fundamentals of geometry creation, materials and process definition and capture, and coherent Product Manufacturing Information (PMI) schemas that eliminate ambiguity. The following sections of this paper outline specific details for accomplishing sound MBD creation.

**Current Practice Challenges**

Today CAD training is just that, pick and click CAD training. It is missing the data and human aspects of Model-Based Definition (MBD) that can be leverage throughout a Model-Based Enterprise (MBE). It is essential that not only do we teach how to use the tools, but that we also teach the most efficient methods to not only author, but to also understand and consume these MBE technologies to increase communication.

Humans and MBE technology intersect at comprehension of:

- The Fundamentals of MBE
- CAD Re-use and Interoperability
- Unambiguous Product Definition

**The Fundamentals of MBE**

Engineers entering the workforce have typically not experienced how engineering data is connected through the digital thread to the rest of the enterprise and the effect that engineering data may have on seemingly unrelated areas of operation. Realistically, today, this knowledge is gained through personal experience, on-the-job training, and mentorship over the first two to four years of employment.

Each education level then builds on MBE awareness topics and transition into building literacy through exposure to details in process, standards and tools. Certificate programs can cover concepts as well as tool knowledge around CAD systems and other product data authoring systems, while more general training can focus on CAD agnostic standards and processes. This approach builds a bridge between general literacy and domain-specific competency. At a competency level, workers can dive into the specific CAD systems, MBD applications, and common digital data consumptions tools, to engage with the problems specific to their own functional area. Mastery comes when students not only apply tools and methods to their specific area, but when they combine their deep domain competency with broad organizational knowledge to implement solutions to both specific and broad problems. Figure 1 illustrates a sample model of how MBE understanding can be built with stackable credentials.

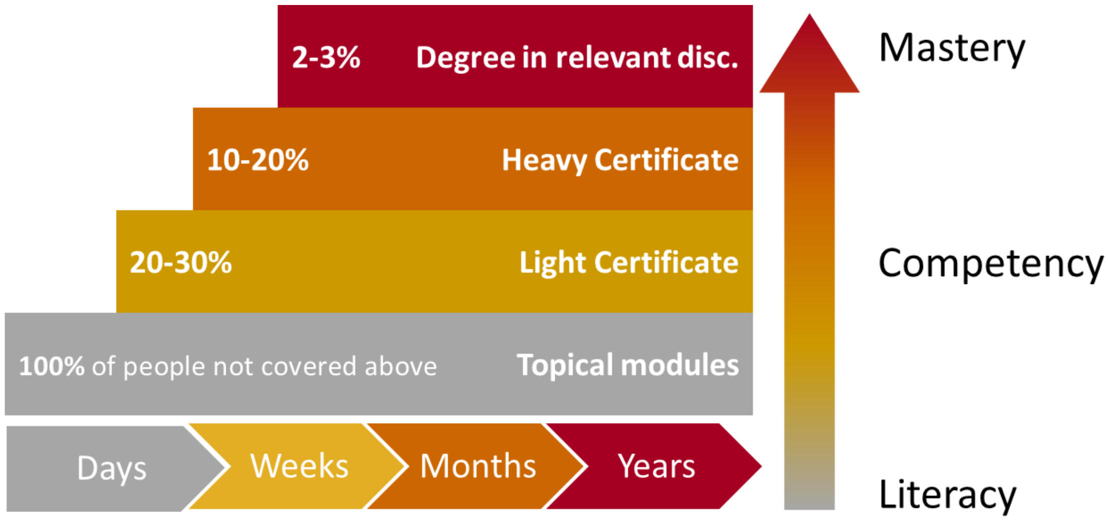


Figure 1: Sample education structure for MBE training and development

A more general structure of job-specific training credentials is shown in Figure 2. Macro credentials are options such a traditional degree or courses. Micro credentials could be traditional courses, but they are most commonly industry-specific training courses. Nano credentials are often focused on specific topics, such as MBD, PLM, or other topics. They are often done in a continuing education approach, with appropriate credits or badges awarded. Pico credentials are also typically dedicated to a specific topic, but in a more detailed way, such as surface modeling for airfoils or applying tolerancing to injection-molded plastic parts. As shown in Figure 2, one of the most obvious differences between these levels is the time scale, with Macro credentials often measured in days or weeks and Pico credentials often measured in singular hours.

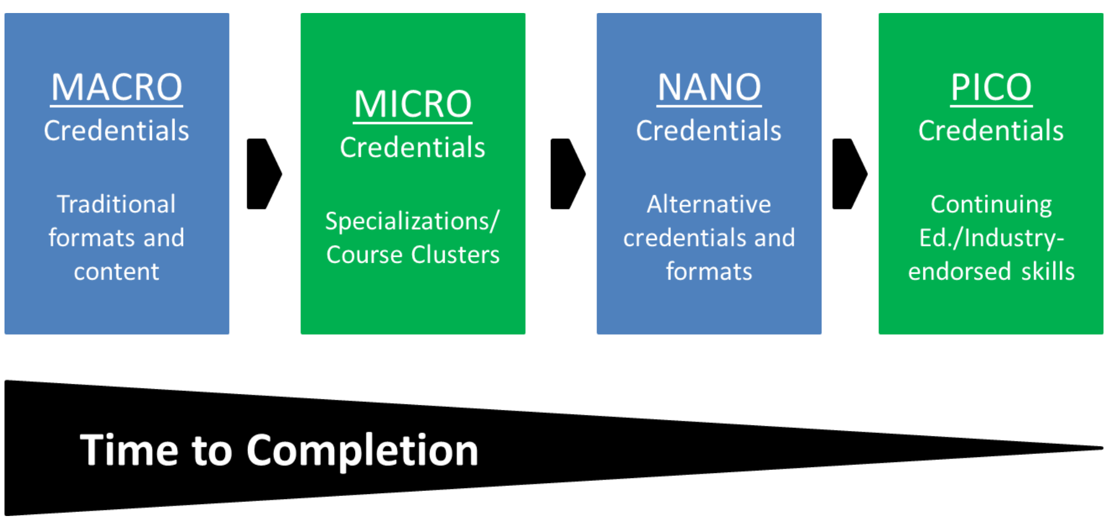


Figure 2: General model for stackable skills

## CAD Data Reuse and Interoperability

Many engineers and designers rightly understand CAD data as a communication tool for design intent. However, the nuances of the consumption of CAD data in other areas of the enterprise including manufacturing, inspection, and quality functions to name just a few are often left unexplored. Well defined CAD models are required to gain the full benefit of CAD data reuse as it is woven into the digital thread of information. Good quality models (includes geometry, annotations and attributes will prevent data failures and tooling clashes as data is translated into various formats required for suppliers to utilize its data. This knowledge is gained through experience, usually at the expense of scrapped parts, CAD rework, and project over-runs which all require valuable time resulting in increased product costs which negatively impact the bottom line.

## Unambiguous Product Definition

The traditional methodologies of capturing product information through manual application of GD&T on a 2D drawing, intended for human interpretation and human consumption only drives ambiguity into the product definition. Misinterpretation of the information and manual programming of the information to devices that automate the manufacture and inspection of the products is an opportunity to avoid human mistakes. Understanding how to disambiguate design intent through a more modern GD&T scheme that is sematic, enables shared input of engineering data by all involved parties in the product's life-cycle from the beginning, allowing for concurrent engineering and efficient reuse of the design, therefore reducing non-conformances which results in lower cost. CNC, Additive Manufacturing, and other computer-based machines able to directly consume 3D geometry consume the PMI directly from the solid model eliminating the need for visual annotation.

## Conclusion

Having a well-educated workforce, able to take advantage of the rich information in a Model-Based Enterprise, will make U.S. manufacturers a more competitive and desirable option to compete with growing overseas companies. Educating through the MBD and MBE knowledge gap will increase the data, technology and human literacy available within the workforce, and provide experienced levels in industry that are innovative and efficient. The manufacturing sector, and the education system that supports it, cannot hide from these technological changes. It would be like trying to away from a tsunami; we will eventually be overtaken. The educational community must embrace these changes, engage with the manufacturing sector, and adapt our respective curricula to meet the needs of a future and a transitioning workforce. The manufacturing sector must be willing to engage with academia and provide its challenges, use cases, and desired outcomes in a compelling manner. By doing so, we can provide the manufacturing sector with the workforce it needs, and we can provide the manufacturing workforce pipeline some sense of stability in an otherwise rapidly advancing future.

## References

1. Giffi, C.A., Rodriguez, M.D., Gangula, B., Michalik, J., de la Rubia, T.D., Carbeck, J., and Cotteleer, M.J., 2015). *Advanced technologies initiative: Manufacturing & innovation.* Retrieved from https://www2.deloitte.com/content/dam/Deloitte/us/Documents/manufacturing/us-indprod-deloitte-and-council-on-competitiveness-advanced-tech-report.pdf

2. Pajula, S., Wellener, P. and Dollar, B. (2018). *2018 manufacturing skills gap study.* Retrieved from https://www2.deloitte.com/us/en/pages/manufacturing/articles/future-of-manufacturing-skills-gap-study.html
3. Bhens, S., Lau, L., and Sarrazin, H. (2016). *The new tech talent you need to succeed in digital.* Retrieved from https://www.mckinsey.com/business-functions/digital-mckinsey/our-insights/the-new-tech-talent-you-need-to-succeed-in-digital
4. Ezell, S.J. (2018, April). *Why manufacturing digitalization matters and how countries are supporting it.* Information Technology & Innovation Foundation.
5. Ezell, S.J., Atkinson, R.D., Kim, I., and Cho, J. (2018, August). *Manufacturing digitalization: Extent of adoptions and recommendations for increasing penetration in Korea and the U.S*. Information Technology & Innovation Foundation.
6. Hendrickson, C., Muro, M., and Galston, W.A. (2018, November). *Countering the geography of discontent: Strategies for left-behind places.* The Brookings Institution. Retrieved from https://www.brookings.edu/research/countering-the-geography-of-discontent-strategies-for-left-behind-places/
7. Husain, A. (2017). The sentient machine: The coming age of artificial intelligence. Scribner: New York. ISBN: 978-1-5011-4467-7
8. National Academies of Sciences, Engineering, and Medicine. 2017. *Building America's Skilled Technical Workforce*. Washington, DC: The National Academies Press. doi: https://doi.org/10.17226/23472.
9. Giffi, C.A., Dollar, B., Gangula, B., and Rodriguez, M.D. (2015). *Help wanted: American manufacturing competitiveness and looming skills gap.* Deloitte Review issue 16. www.deloittereview.com.
10. Wikipedia https://en.wikipedia.org/wiki/Gestalt_psychology
11. ASME Y14.41-2013