AUTODESK™ | ASME SETTING THE STANDARD

Future of Manufacturing

New workflows, roles & skills to achieve Industry 4.0 business outcomes

Research report

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Future of manufacturing

The manufacturing industry currently faces a confluence of changes that will significantly transform the roles, skills, and workflows of mechanical engineers, manufacturing engineers, and machinists over the next 10 years. These changes are driven primarily by pressures on businesses to achieve the outcomes of improved productivity, production output, profitability/costs, competitivity, and sustainability and circular design. There is expected to be a greater convergence of the mechanical and manufacturing engineering roles and a significant transformation of the CNC (computer numerical control) machinist role.

Executive summary

The manufacturing industry sits at a crossroads. One path leads to a cavalcade of Industry 4.0 technologies that presents a generational digital transformation opportunity to advance manufacturing, improve business outcomes, and regain a competitive position for the future. The other path is the narrow, business-as-usual route fenced in by Industry 3.0 or earlier technologies that limit the capacity to automate, scale, and optimize a business to meet changing market needs.

As firms contemplate a decision, industry challenges are mounting with increasing competition, rising costs, and shrinking time-to-market schedules across vertical markets and manufacturing operations worldwide. To compound the situation further, the market demands more complex, customized, and electronics-based products, while businesses strive to adopt smarter, leaner, and more sustainable manufacturing practices to compete globally.

All industry, market, and business indicators point toward the Industry 4.0 path. It is the most realistic option to achieve the desired business outcomes and create a manufacturing firm that can evolve with the rapidly changing industry. This shift presents a strategic opportunity to transform business processes, manufacturing workflows, and the technological portfolio to enable a connected, flexible, and responsive manufacturing industry.

Emerging technologies include:

- Design for manufacturing (DfM)
- Operations technology (OT) infrastructure
- AI/ML-driven technologies like generative design
- Cloud-based software platforms like integrated computer-aided design and manufacturing (CAD/CAM)
- Project lifecycle management (PLM)
- Manufacturing execution systems (MES)
- Business intelligence (BI) solutions
- Centralized data management for collaboration and data analysis

By taking a system-level approach, firms will be able to develop advanced manufacturing strategies and technology adoption plans that will deliver the connected, collaborative, and continuous manufacturing workflows and workforce needed to achieve their business goals and outcomes. (See Industry 4.0 transformation infographic on the next page.)

New DfM and digital skills will be required by mechanical engineers, manufacturing engineers, and CNC machinists to properly equip them to perform the jobs required to support new workflows. Manufacturing education programs need to recognize the significant skills gaps between graduates and industry workforce requirements and take steps to create new advanced manufacturing coursework that teaches the in-demand industry concepts, skills, and competencies. Success depends on developing new manufacturing education pedagogies to effectively train the necessary Industry 4.0 technologies and skills. These new skills categories are:

- Technical/hard skills (AI/ML, programming, data analysis, visualization)
- Soft skills (collaboration, communication, problem-solving)
- Interdisciplinary skills (systems engineering, automation, sustainability, supply chain management, PLM, integrated CAD/CAM)

To provide industry and academic guidance for advanced manufacturing, ASME and Autodesk conducted a research study from August 2021 through May 2022 that investigated and identified the future workflows and skills needed for mechanical engineering, manufacturing engineering, and CNC machinist roles over the next decade. (See research process on page 11.)

Each role will evolve in its own way, but the study shows that the necessary new skills will consist of a purposeful combination of common skills (both hard and soft skills) that apply to all three positions, and interdisciplinary skills.

Transform to improve business outcomes

Today

Disparate. Disconnected. Different.

- Mechanical engineer
- Manufacturing engineer
- CNC machinist
- Production

Industry 3.0

Legacy CAD/legacy CAM

Task-specific robotics and application-specific automation; disparate data applications

Siloed workflows and teams

Digital transformation

Collect and organize data on a single platform

Connect teams to access and exchange data

Converged cloud applications

Workflow transformation

Redesign workflows

Reimagine roles and responsibilities; upskill and reskill

Collaborate across disciplines leveraging cloud solutions

Business transformation

Leverage emerging technologies like AI/ML, GD, AM, cobotics

Visualize and analyze data for process automation and optimization

Remove current silos

Tomorrow

Converged. Connected. Collaborative.

Mechanical engr.
Manufacturing engr.
CNC machinist
Production

Industry 4.0

Converged cloud and data platforms (e.g., integrated CAD/CAM)

AI/ML applications, generative design, data analytics, AM, cobotics

Unified production—orchestrated across distributed systems

Connected workflows and cross-functional collaboration

Common hard skills according to industry respondents will include an increased aptitude for AI/ML technologies such as generative design, which will help optimize designs for criteria including cost and performance. According to 324 survey respondents (detailed on page 14), mechanical engineers need an increasing knowledge of AI/ML to improve product development (56%); manufacturing engineers to advance and optimize the manufacturing process (61%), and CNC machinists to operate and manage production (56%). Having design for manufacturing skills and knowledge across the organization will help these job roles collectively contribute to improving manufacturing best practices. In fact, 90% of all survey respondents affirm that teaching deeper DfM knowledge is the most effective way for academia to develop the future manufacturing workforce. Large majorities of the engineers surveyed see the need for increasing DfM skills over 5-10 years for both mechanical engineers (84%) and manufacturing engineers (88%).

Other digital skills such as modeling, simulation, and data analysis will be important in many roles as firms become more data-driven and automated.

Common soft skills necessary for all roles include creative problem solving, communication, and collaboration. Almost 60% of the industry engineers surveyed expect the three positions to collaborate more closely. This increased collaboration will require the need for better communication and group problem-solving as new workflows converge. Cloud collaboration platforms that break down geographic barriers and bring teams together in new ways will enable all three job functions to collaborate more efficiently.

Mechanical engineers will play key roles in developing better products that are designed for manufacturability and are leaner, smarter, and more sustainable. Resulting innovations will create new business models based on intelligent product designs with data feedback loops that help improve future product iterations. Required mechanical engineering skills will expand beyond their traditional scope to include the abilities to design with electronics and to design for product modularity that will extend the product lifecycle.

To successfully design more complex products, mechanical engineers will need increasing levels of hard skills for technologies like advanced additive manufacturing and a variety of CAD, CAM, CAE (computer aided engineering), and PCB (printed circuit board) software capabilities. Survey results from 222 engineers anticipate their work increasing with CAD/CAM (67%), PLM software (73%), and design for additive manufacturing (71%). Additionally, 102 academics foresee an increasing emphasis on generative design (80%), and programming techniques (75%).

Manufacturing engineers will lead the strategic efforts to improve and adopt advanced manufacturing techniques and processes. They will determine how to apply technologies like AI/ML to improve automation results and adopt smart manufacturing practices like programming production lines, managing distributed manufacturing locations, and deploying real-time production monitoring systems. They will need to design and implement manufacturing systems to improve time-to-market and at the same time reduce cost, waste, and defects. This role will strive to find the right resource utilization across the human workforce and production machinery including robotics, additive manufacturing, and digital twins, using production data analytics and visualization to find opportunities for efficiencies.

CNC machinists will take the biggest step forward among the three positions as their role is significantly enhanced by Industry 4.0 technologies. Their positions will expand and shift to include managing and programming robots (autonomous machines that perform tasks without human control) and cobots (artificially intelligent robots that perform tasks in collaboration with humans), as well as analyzing real-time production output, shop-floor inspection, and participating in quality assurance (QA) and quality control (QC). Machinists will need to develop new skills in AI/ML for production, five-axis machines, additive manufacturing, and hybrid manufacturing (using additive and subtractive manufacturing in tandem). They are also expected to collaborate more with engineering teams and be more involved with upstream processes like design, which will require greater knowledge of CAD/CAM software. Over the next 5-10 years, industry professionals (n. 51) state the top CNC machinist hard skills required will be CAM software (86%) and CAD software (82%).

Interdisciplinary skills will also be vital with the increased collaboration between mechanical engineers, manufacturing engineers, and machinists. The need for systems engineering skills among engineers are expected to increase over the next 5-10 years, and both implementing automation and pursuing sustainability goals fall under the interdisciplinary banner.

The proliferation of common and interdisciplinary skills across these three key manufacturing roles reinforces the efficacy of utilizing software platforms to connect workflows, store centralized data and share it across workflows and team roles, and assist the collaboration toward joint product goals and business objectives.

To prepare for this transition that is already underway and soon to accelerate, manufacturing education needs close examination and reformation as soon as possible to keep up with the rapid changes in the workplace. Incremental changes to workforce training will not be enough. Rather, academia should work closely with industry to develop new pedagogies to teach and develop interdisciplinary knowledge and skills. People need to begin learning Industry 4.0 technological skills as their new baseline of educational development. Given the emphasis on increasing the generative design, AI/ML, and CAD/CAM skills among engineers and machinists, there is widespread support for using certifications and credentials to endow those skills as an alternative or supplement to degree programs. Among all survey takers, 84% agree it will be very effective for industry and academia to jointly develop more certification programs.

Industry can contribute crucially to manufacturing education by providing internships, co-op programs, certifications, and best practices. But with business pressures irrevocably driving manufacturing to Industry 4.0, academia must take action today to align with trends now, because modernizing educational practices will not be an overnight transition.

Propelled by key business drivers such as cost pressures, supply-chain disruption, productivity, and sustainability, these technological, workflow, and operational changes demand new workforce skills for optimal results. Without fundamental end-to-end changes in education from academia to industry, we risk widening the skills gap. This collective challenge of successfully transitioning to Industry 4.0 will take a transformation in both industry practices and training programs. Such a transformation will take time, but there is not much time to waste. This paper discusses the significant changes ahead in the roles and workflows for mechanical engineers, manufacturing engineers, and CNC machinists, and suggests strategies for arriving at the better outcomes we know are possible if we take the proper steps to get there.

> "I feel there is need for the degree. I look at the degree as a foundation. The micro credentials and the credentials, yes, they are very important. They are very important in the sense of new knowledge, smart manufacturing, how to do manufacturing, artificial intelligence, machine learning. These are the new degrees."

Raju Dandu, PhD
Professor; Director, Bulk Solids Innovation Center
Kansas State University Salina

Introduction

The global economy has created intense competitive, cost, and time-to-market pressures for the manufacturing industry. In response, companies must strive for greater productivity, higher profitability, and more efficiencies. These shifts are driving manufacturing toward wholly digital processes, while supply chain risks and the goal of circular product lifecycles require better upfront planning and process modeling in advance of physical production.

However, current design and manufacturing workflows are disjointed, serial, and siloed, which leads to rework and other inefficiencies that limit businesses' ability to increase output, improve quality, and reduce waste. Such processes are still based on decades-old technology and resources from Industry 2.0/Industry 3.0. But today's Industry 4.0 technology upgrades the resources available to design and manufacture.

To advance the future of work, we need to rethink the way we work. We need a systems-level transformation for collecting, analyzing, and sharing centralized data; redesigning manufacturing workflows and job functions; and adopting technologies like generative design and other CAD/CAM solutions that leverage AI/ML, automation for programmable processes (such as additive and subtractive manufacturing and OT), and interoperable data for manipulating production and supply chain operations in real time.

> "The demand of the customer is to get things quicker, cheaper, with less rework, and with greater precision."

Jeffrey Reed
Director, Engineering
Northrop Grumman Corporation

> "All the data will be in the Cloud where engineers will work with global teams utilizing the same valuable data."

Vukica Javanovic, PhD
Assoc. Professor; Interim Department Chair
Mechanical Engineering Technology
Old Dominion University

However, to improve system-wide manufacturing outcomes, the traditional roles of mechanical engineers, manufacturing engineers, and CNC machinists must change. The World Economic Forum (WEF) in 2020[1] estimated that 50% of all manufacturing employees will need reskilling. Unfortunately, the educational system is not keeping up with the pace of change within manufacturing jobs to prepare tomorrow's workforce adequately. Much of today's US engineering education curriculum has not changed since the 1955 Grinter Report, which emphasized mathematics and physics over project-based learning and hands-on applications. So, many current curricula lack the modern developments in digitalization. Some engineering programs teach an almost 80-year-old pedagogy with software packages 30+ years old. As a result, skills gaps are widening among new manufacturing workers.[2]

Manufacturing and engineering education must take a systems-level redesign perspective to develop and optimize the workflows changes needed in the manufacturing industry. One of the key objectives of the educational redesign is to "reduce the time to talent." There will still be a need for advanced degrees, but swifter alternatives that teach students the skills required for Industry 4.0 manufacturing careers in a shorter timeframe need to proliferate.

> "We need to let go of this die-hard commitment of designing curricula to produce engineering professors. We need curricula to produce high-quality engineers that will be working in industry. The basics of US engineering education were set back in the mid-50s and the paradigm on which the curriculum was based hasn't changed in 50+ years."

Pierre Larochelle, PhD
Department Head and Professor
South Dakota Mines

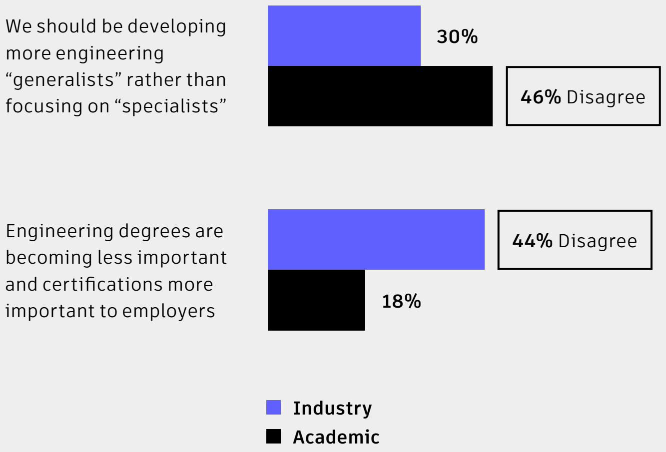
1 WEF, "The Future of Jobs Report 2020," https://www.weforum.org/reports/the-future-of-jobs-report-2020/in-full/infographics-e4e69e4de7.

2 Sorby, S., Fortenberry, N., and Bertoline, G., 2021, "Stuck in 1955, Engineering Education Needs a Revolution," Issues Sci. Technol., https://issues.org/engineering-education-change-sorby-fortenberry-bertoline/.

Figure 1:
Attitudes about education and the future of manufacturing (academia vs. industry % who disagree)

There is a significant split in academia about developing engineering generalists versus specialists. Similarly, within industry, there is a significant split about the value of engineering degrees versus certifications.

Base: 222 Industry and 102 academic professionals



Recognizing that current manufacturing training will not meet the requirements of an Industry 4.0 workforce, ASME, in partnership with Autodesk, conducted a multiphase research project to define the future job descriptions, typical workflows, and expected duties/skills for mechanical engineers, manufacturing engineers, and CNC machinists over the next 5-10 years. We broke down the traditional workflow for these positions to examine how to improve overall design and manufacturing outcomes across the system.

We sought how to break through constraints and incorporate all the innovations available to advance the manufacturing industry with connected, collaborative, and circular/continuous workflows, technologies, and processes designed to achieve better business outcomes.

Considering the increasing adoption of Industry 4.0 over the next 5-10 years, this study sought to answer the following questions:

- How will the workflows for mechanical engineers, manufacturing engineers, and machinists evolve?
- What skill set and mindset will people need to thrive in these roles?
- How are these roles changing?
- How will those role changes affect training and hiring?
- How can industry, academia, and government ensure that students and professionals of all backgrounds will develop the skills and mindset they need to thrive in these roles?
- What steps should academia take to update its pedagogy to train the curricula needed?

Research process

Phase 1

Literature review

Review of 77 existing sources

Review of existing curricula in US and UK programs

Phase 2

Interviews

30 Individual interviews

10 Academics

20 Industry: US and UK

Phase 3

Surveys

324 Respondents

Academics and industry: US, Canada, and UK

Phase 1: Existing literature review

To address these questions, Phase 1 of the project comprised an extensive analysis of the existing literature on related topics from academic, government, and industry sources. We created a desk research outline to help guide the literature search, which included academic and gray literature from 2018-2021.[3] This outline mined strategic documents from the United States, United Kingdom, European Union, and key industry reports to identify externalities and emerging technologies impacting future work roles. We supported and supplemented the resulting insights with other academic and gray literature. Due to the rapidly evolving nature of this topic, non-academic articles further substantiated our claims.

3 Literature or research produced outside of academic settings, including industry reports, government documents, and working papers

We created typical workflows reflecting the current state of each occupation’s tasks and work activities with details from the Occupational Information Network (O*Net), a free online database of occupational-related information specific to the United States, and Burning Glass, a job market data analytics platform. We also mapped the required skills and associated technologies for each stage in the workflow based on all of the above sources and our interpretations. These identified tasks, skills, and associated technologies are representative but not exhaustive.

Top current skills were selected from O*Net and Burning Glass from those most requested in the last year. The skills Burning Glass identified with the fastest projected growth over the next two years, as well as skills identified through recent literature were selected as the top-growing skills. This review focused on mechanical engineers who design products, so technical skills such as plumbing and HVAC were removed. Soft skills such as “physical abilities” were also removed for mechanical and manufacturing engineers, as they were outside the scope of interest. However, the “physical abilities” skill was included for the machinist role because it is relevant to how machinists’ work will change in the future.

Lastly, we created future workflows by synthesizing insights from the literature on externalities driving changes in these professions and on emerging technologies affecting product design and manufacturing. We then mapped the future workflows onto the current workflows. Those maps identify the current tasks that emerging technologies will either assist, transform, or replace, and higher-level shifts required by technological and non-technological externality trends.

For Phases 2 and 3, we conducted 30 interviews and 324 online surveys to expand upon Phase 1’s findings, focusing on how the three featured roles’ workflows and job descriptions might look 10 years from now. Phase 1 results informed the survey and interview questions for Phases 2 and 3.

Phase 2: Interviews

We conducted in-depth telephone interviews through ASME and Beacon Technology Partners LLC with 30 select thought leaders—20 from industry and 10 from academia.[4] Interview discussion topics included:

- Changing workflows and skill set expectations for mechanical engineers, manufacturing engineers, and CNC machinists over the next decade
- The impact of CAD/CAM software, generative design, 3D manufacturing, digital twins, interdisciplinary knowledge and collaboration, data analytics and programming, and other topics
- Industry, government, and academic requirements to facilitate this pathway toward the necessary knowledge and skills
- How to encourage "lifelong learning" through project-based curricula, elevating the image of manufacturing, collaboration with community colleges, apprenticeship vs. internships, how small-to-midsized manufacturers can provide training, and other issues

4 "Industry" is defined as for-profit entities working toward the creation or production of engineering-related products or resources; "academia" is defined as anyone working primarily at an academic/educational institution, dedicated to education and research, which grants academic degrees

Phase 3: Surveys

An online survey distributed from February 1 to March 4, 2022 collected 324 usable responses (representing a confidence interval of ± 3.1% in aggregate).

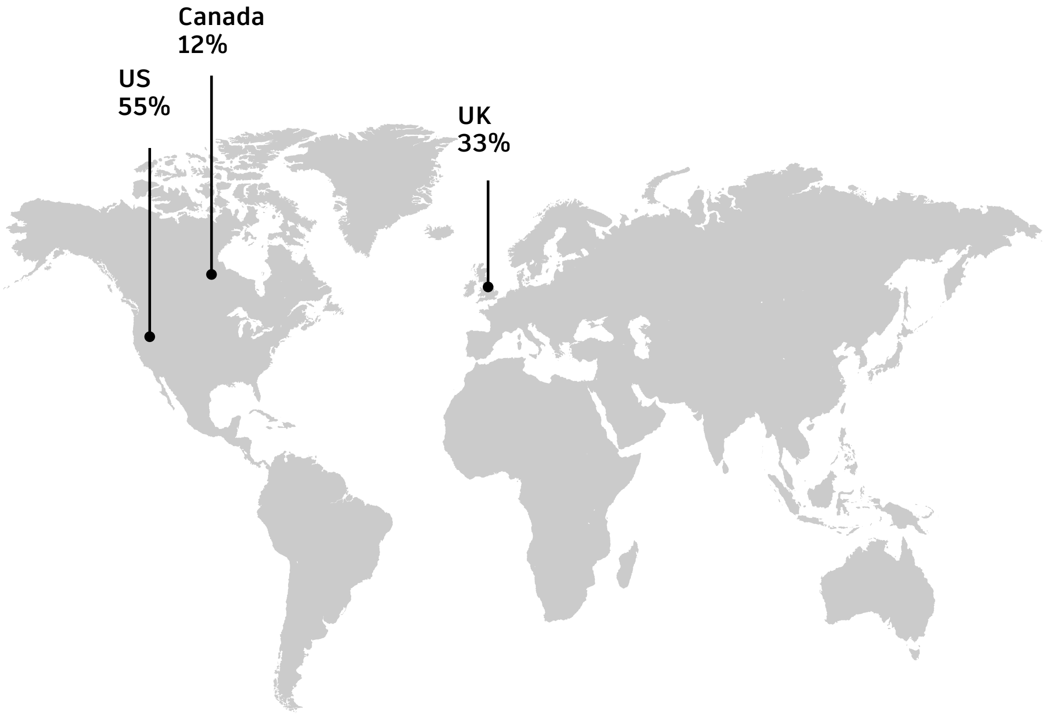


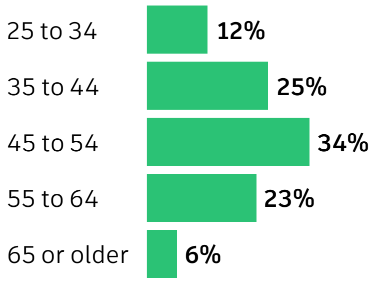
Figure 2:
Phase 3 survey respondents demographics

North America
67%

United Kingdom
33%

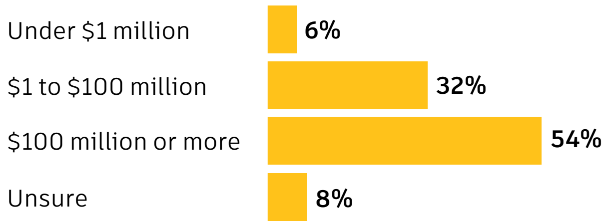
324
Responses

Age



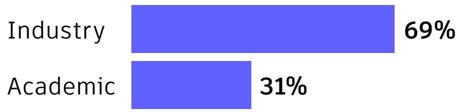
Mean age - 47.8 years

Organization size, by revenue



Mean annual revenue = $72.5 Million

Status



Industry trends drive change

As accelerating industry changes mount, they create a challenging manufacturing environment. Our survey results clearly indicate that the leading industry and digital transformation drivers are improving productivity, increasing profits, and shorter product (development) life cycles (see figure 3).

Manufacturing firms continually strive to automate and streamline operations to yield more output and higher-quality output. However, optimizing production lines presents further challenges, because many production sites and subcontractors are distributed across the globe, and often utilize different machinery and systems technology.

Meanwhile, as more and more firms initiate sustainability efforts to reduce their environmental impact, that places further requirements on their existing manufacturing processes and systems. With these business and industry demands, firms feel increasing pressure to find solutions to these core business challenges.

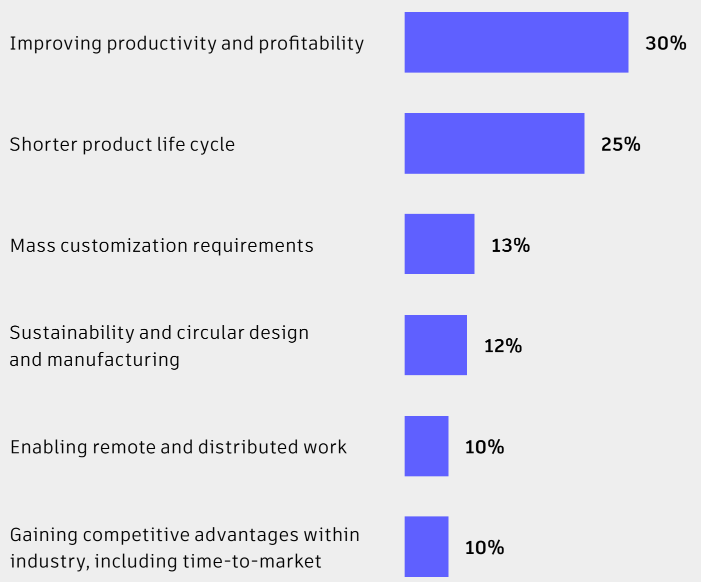
Many companies look to technology for answers. Available Industry 4.0 technologies afford companies the opportunity to identify and adopt technologies to advance their businesses with a digital transformation. AI/ML-based technologies, software platforms, robotics, the Internet of Things (IoT), cloud data storage, and other technologies work synergistically to form a powerful digital infrastructure with new instrumentation and programming capabilities. With that, manufacturing teams can rethink the way they collaborate and work together. However, this technological shift has also created more competition, prompting firms to determine their course of action to stay relevant.

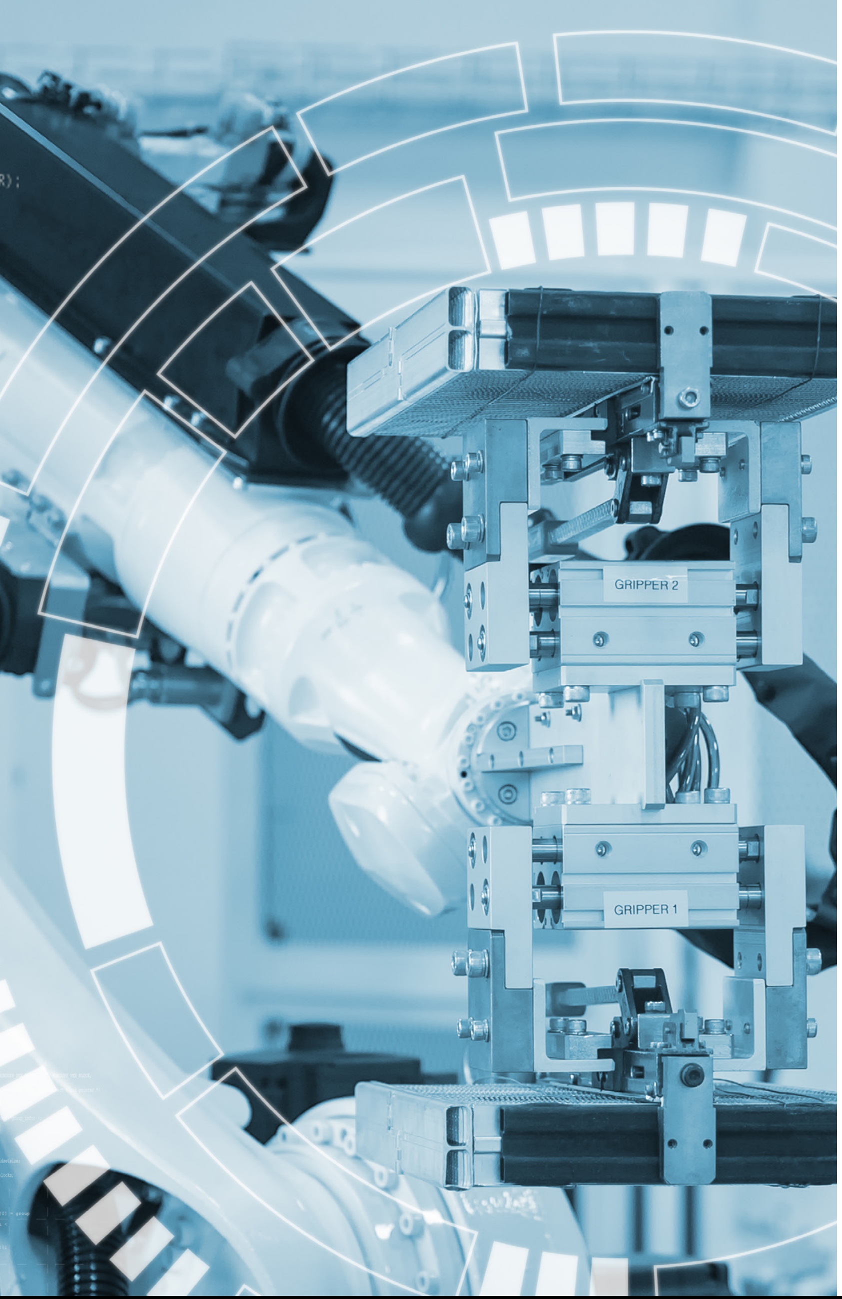
Businesses recognize the need to adapt and evolve their technology infrastructure, operations, workforce, and skills to improve their output, bottom line, and stay competitive. But how?

Figure 3:
Industry & digital transformation trends driving change

Productivity, profitability, and shorter product (development) cycles are challenging the industry with additional demands for more customizable and sustainable designs.

Base: 171 Mechanical and manufacturing engineers





Business challenges

To achieve meaningful gains in productivity, profitability, and time-to-market, companies must undergo a business transformation that implements the new processes, workflows, technologies, and skill set changes that will generate manufacturing improvements for lasting results.

Our research shows a clear difference between the skills and technologies that typical mechanical and manufacturing engineers and machinists currently wield, and the skills and technologies they will need to possess over the next two years and into the next 5-10 years.

Current business processes, workflows, and skills are based on Industry 2.0 or 3.0 methods and technologies that fundamentally limit manufacturing. Firms struggle with disjointed workflows, disconnected systems, and siloed information and systems that make it virtually impossible to gain stepwise improvements across their operations. However, the business motivation for lowering costs, increasing productivity, and furthering sustainability is pushing manufacturing at an accelerating pace toward Industry 4.0 technologies and connected, collaborative workflows. Therefore, continuing business as usual—both as it pertains to these three key manufacturing roles and to the currently disjointed, disconnected, and siloed workflows—will simply not achieve the necessary business outcomes.

Only by enacting a digital transformation that reengineers the workflows, applications, digital and operational infrastructure, and data management in the manufacturing solution stack, along with new skills training to design and conduct the work, will companies attain the significant improvements in business outcomes. These innovative steps will enable firms to obtain the manufacturing efficiencies, cost reductions, and differentiation needed to advance their businesses.

Industry system-level solution approach

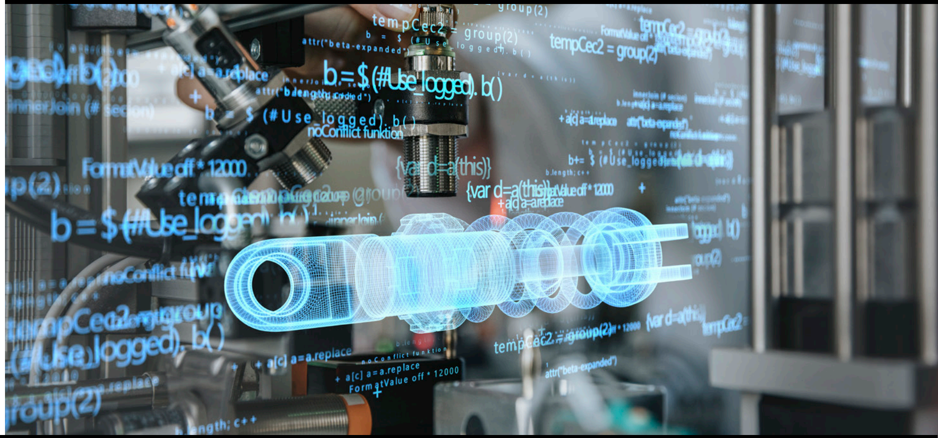
To capitalize on Industry 4.0 technologies, firms need to examine their system-level manufacturing operating model and determine which technologies to integrate and how to apply them to create the new workflows that will advance their manufacturing process. Each new technology creates an opportunity to redesign and streamline work. It is important to understand how these technologies will impact the employee roles within the workflow, so the proper education and skills training can be developed to support the workforce through the digital transformation.

In this section, we take a bottom-up approach to examining how each technology solution layer supports and enables new workflows and business process improvements during an Industry 4.0 digital transformation. This will help explain the new skills and education required.

Data informs the operations. Product design models, manufacturing costs, production schedules, and CNC machine programs are all forms of valuable data. The more information teams can access and obtain when they need it, the more intelligent workflow decisions can be made to guide and inform each step in the manufacturing process. Team members will create, share, and consume data, so they need the skills to contribute, manage, and analyze centralized data stores.

> "I think it's just the interpersonal skills to be able to work across the different disciplines because we all know, any of us who have spent time in manufacturing, the personality of a machinist versus the personality of an engineering person may be completely different. I think it's being able to effectively communicate what's going on in the machine shop to those other disciplines."

Timothy Robertson
ATDM Technical Program Manager
Institute for Advanced Learning and Research



Infrastructure is essential to network and connect teams, systems, and applications. Digital and operational infrastructure provides an overall view of the manufacturing systems and operational status to manage performance and output. Operational systems dashboards will provide visibility and analytics to manage and operate the end-to-end system operations seamlessly from design, engineering, manufacturing engineering, and production. Automation opportunities need to utilize data analytics and visualization technologies to determine how to schedule and run the systems to be more efficient and scalable.

Applications and software platforms help consolidate tools, connect workflows, and facilitate work collaboration. For instance, an integrated CAD/CAM/CAE/PCB software platform now merges the design, engineering, and manufacturing workstream providing mechanical engineers, manufacturing engineers, and CNC machinists with a common tool to simplify and streamline what was traditionally a serial sequence of discrete work tasks performed with standalone desktop tools, using different file formats, and running independently. Now, a virtual team can collaborate to perform the necessary tasks much more efficiently using a cloud-based software platform.

Workflows define work relationships across roles and how teams collaborate to complete the work. Continuing with the integrated CAD/CAM example, a redesigned engineering workflow can take advantage of new AI/ML technology capabilities like generative design. For mechanical engineers, generative design completely changes how product design options are created to optimize for specific design parameters like cost, weight, and durability. The design parameters selection can be intelligently determined based on supply chain availability and additive design capabilities in the production line, all enabled by centralized data captured across the system.

Newly designed business processes can improve business outcomes. For example, new agile project management methodologies that are flexible, quick, and continuous enable rapid prototyping and support more modular product design and manufacturing. These new processes can increase productivity, reduce costs, and expedite time-to-market.

Industry insiders acknowledge that remaining competitive and producing lasting business value requires rethinking workflows to facilitate better collaboration. Businesses also need the flexibility to create processes that easily integrate with other solutions, enabling the most seamless interaction from ideation to end-product.

In this collaborative and connected work environment, new soft skills will be as critical as hard skills for all roles. Empathy, communication, conflict resolution, problem-solving, and team-building skills will be essential to work more effectively across manufacturing disciplines and teams. Such soft skills are also needed to socialize and support the new connected and collaborative workflows across the organization. Since the future is collaborative, engineers must continue to develop their soft skills to help them improve their communication and teamwork abilities, evolving their mindset from working on isolated components to teams, systems, and interdisciplinary projects.

Future workflows, roles & skills

Industry voices have clearly called out the large gaps between the jobs skills required and the candidates' skill sets. The skills gap will only widen as manufacturing firms accelerate their digital transformation to Industry 4.0. Employers increasingly seek more advanced computing and data analysis skills that enable core production workers to program a CNC machine for a new turning job, manufacturing engineers to automate and streamline manufacturing production lines, and mechanical engineers to optimize designs for cost with technologies like generative design. To train the new manufacturing workforce, educators need to strike a balance between direct, hands-on skills development on one side and design for manufacturing (DfM) and operations research education on the other, so that graduates can contribute to the design and implementation of more efficient manufacturing workflows and processes.

Our study identified current in-demand skills for mechanical engineers, manufacturing engineers, and CNC machinists, and the new skills required to succeed in the next 5-10 years. In short, the additional Industry 4.0 technology knowledge and skills needed far exceed the current skill sets.

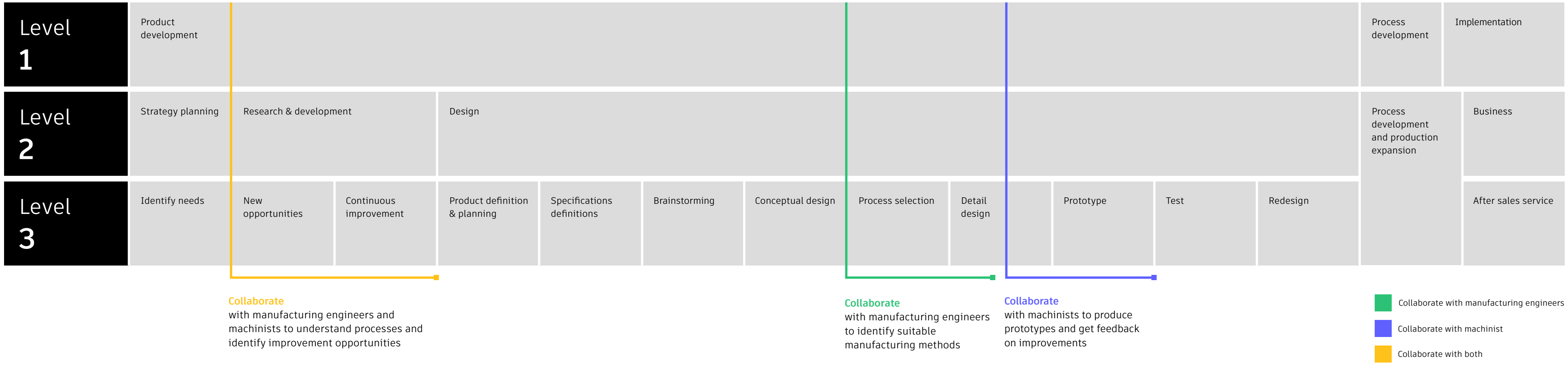
Each role will evolve in its own way, but there are also some consistent changes common to them all. New skill sets fall under three categories: hard skills—knowledge and capabilities required to perform explicit job duties; soft skills—interpersonal qualities like communication, collaboration, and problem solving; and interdisciplinary skills—abilities for integrating knowledge across the different manufacturing functions, as job duties evolve to be more connected and collaborative across the end-to-end manufacturing process. For example, almost 60% of the industry engineers surveyed (n. 171) expect the three positions to collaborate with each other much more.

Across the three positions, there are an increasing number of common skills, such as DfM and AI/ML technologies, like generative design, which signals the need for a shared understanding of key concepts and capabilities to enable productive collaboration. Industry respondents (n. 222) say mechanical engineers need an increasing knowledge of AI/ML as it pertains to product development (56%), manufacturing engineers need it as it pertains to the manufacturing process (61%), and CNC machinists need it as it pertains to production (56%).

A thorough grasp of DfM skills will be foundational and increasingly important across all the manufacturing roles. 90% of all 324 survey respondents stated that teaching deeper DfM knowledge was the most impactful way for academia to develop the future manufacturing workforce.

Figure 4: Current mechanical engineer workflow

Note: See Appendix A for future connected workflow diagram and key collaboration points enabled by new technologies and tools.



Mechanical engineers today are primarily responsible for the research, planning, design, development, testing, and continuous improvement and redesign of new and existing products, machines, and tools, with the bulk of the work represented in the design stage (see figure 4). Some mechanical engineers (MEs) also focus on strategy planning and creating after-sales services. Most mechanical engineers have at least a bachelor's degree (83%), although some have associate degrees (7%) or no degree (5%).[5]

Current mechanical engineer skills and technologies used:

- Computer aided design (CAD)
- Analytical software such as Matlab and Minitab
- Enterprise resource planning (ERP) software
- Programming tools
- Financial analysis software

5 O*Net, "Mechanical Engineers 17-2141.00," https://www.onetonline.org/link/summary/17-2141.00

Mechanical engineers in 5-10 years will play key roles in developing better products that are designed for manufacturability and are leaner, smarter, and more sustainable. Resulting innovations will create new business models based on intelligent product iterations. Required mechanical engineering skills will expand beyond their traditional scope to include the abilities to design with electronics and to design for product modularity that will extend the product lifecycle.

To successfully design more complex products, mechanical engineers will need increasing levels of hard skills for technologies like advanced additive manufacturing and a variety of CAD, CAM, CAE (computer aided engineering), and PCB (printed circuit board) software capabilities. Survey results from engineers anticipate their work increasing with CAD/CAM (67%), PLM software (73%), and design for additive manufacturing (71%). And academics foresee an increasing emphasis on generative design (80%), and programming techniques (75%).

With an increasing focus on additive manufacturing, mechanical engineers will need to utilize AI/ML-based generative design to facilitate product design for manufacturability (see figure 6).

Generative design has tremendous potential to reduce time-to-market and material use while maintaining product strength, durability, and other product qualities. Of 171 mechanical and manufacturing engineers surveyed, 65% of respondents believe mechanical engineers will need to adopt generative design techniques within the next 5-10 years (see figure 6).

> "The future engineers would have a requirement of being able to at least low code—potentially having the ability to write macros and scripts in the CAD system where they work."

Dmitry Ovsyannikov
Chief Technology Officer
Matre

> "I think that machine learning and AI will also greatly change the mechanical engineer. I think they will need to have more in-depth understanding of the manufacturing processes because the amount of data that's going to be available is going to be insane, so they're going to need to put that into the design process."

Timothy Robertson
ATDM Technical Program Manager
Institute for Advanced Learning and Research

> "The barriers between engineering and manufacturing are coming down. I think 10 years from now you are going to see manufacturing engineers and mechanical engineers with equivalent degrees coming out of college."

Jeffrey Reed
Director, Engineering
Northrop Grumman Corporation

> "One of the major skills the mechanical engineering student is lacking is that manufacturing aspect, which has to be integrated into the design. It's not only designing something, but having the vision: How will it be manufactured? How will it be handled by the users?"

Raju Dandu, PhD
Professor; Director, Bulk Solids Innovation Center
Kansas State University Salina

With the adoption of IoT and other Industry 4.0 technologies, large volumes of operational data will be available. Engineers will need the tools and skills to extract meaningful information and insights from the data. Of 171 mechanical and manufacturing engineers surveyed, 69% think mechanical engineers will need data analysis and visualization skills in their core skill set. Some programming (particularly low code/no code methodologies) knowledge will also be needed to identify areas to optimize and automate.

To create smarter, more circular products more efficiently, 84% percent of industry respondents said mechanical engineers will increasingly need to apply DfM principles in their work. DfM creates more efficient workflows with less need for rework. Most organizations no longer accept the "throw it over the wall and see what happens" approach. There is a greater emphasis on project-based learning and integrated end-to-end design platforms, which converge the design and production stages.

Collaboration is also key to succeed with DfM. Designers need to engage and interact with machinists and manufacturing engineers to gather direct feedback on their products. Through more frequent discussions with team members, previous engineering silos will begin to collapse, and a more open and collaborative work environment will evolve. Our data found that 90% or more of industry respondents strongly believed that mechanical engineers will increasingly need to develop their soft skills in creative problem solving, collaboration, and communication.

Mechanical engineers will become increasingly interdisciplinary as they design and engineer complex integrated solutions that will require mechanical, electrical, and software engineering knowledge. According to our survey of 171 mechanical and manufacturing engineers and 102 academics, there is a strong consensus (77% and 87% respectively) that MEs will need system-engineering skills. And 79% of industry respondents believe MEs will need a working awareness of electrical and software engineering principles. In North America, 59% of 217 survey respondents said MEs will need to focus on sustainability too, which takes into consideration the whole product lifecycle.

Future mechanical engineers skills needed

Hard skills

Generative design

AI/ML for product development

Design for manufacturing (DfM), including knowledge of the subsequent manufacturing processes (for engineers involved in the design phase)

Knowledge of coding

3D modeling/design with a focus on aesthetics

Data analytics and visualization

Prototyping

Engineering simulation and digital twin simulation

Soft skills

Creative problem-solving

Collaboration as individuals/teams

Communications (written/verbal)

Interdisciplinary skills

Experience with systems engineering

Knowledge of electrical and software engineering

A focus on sustainability

Figure 5:
Status of manufacturing technology initiatives

Industry 4.0 technologies will continue to see increased adoption over the next decade.

Base: 171 Mechanical and manufacturing engineers

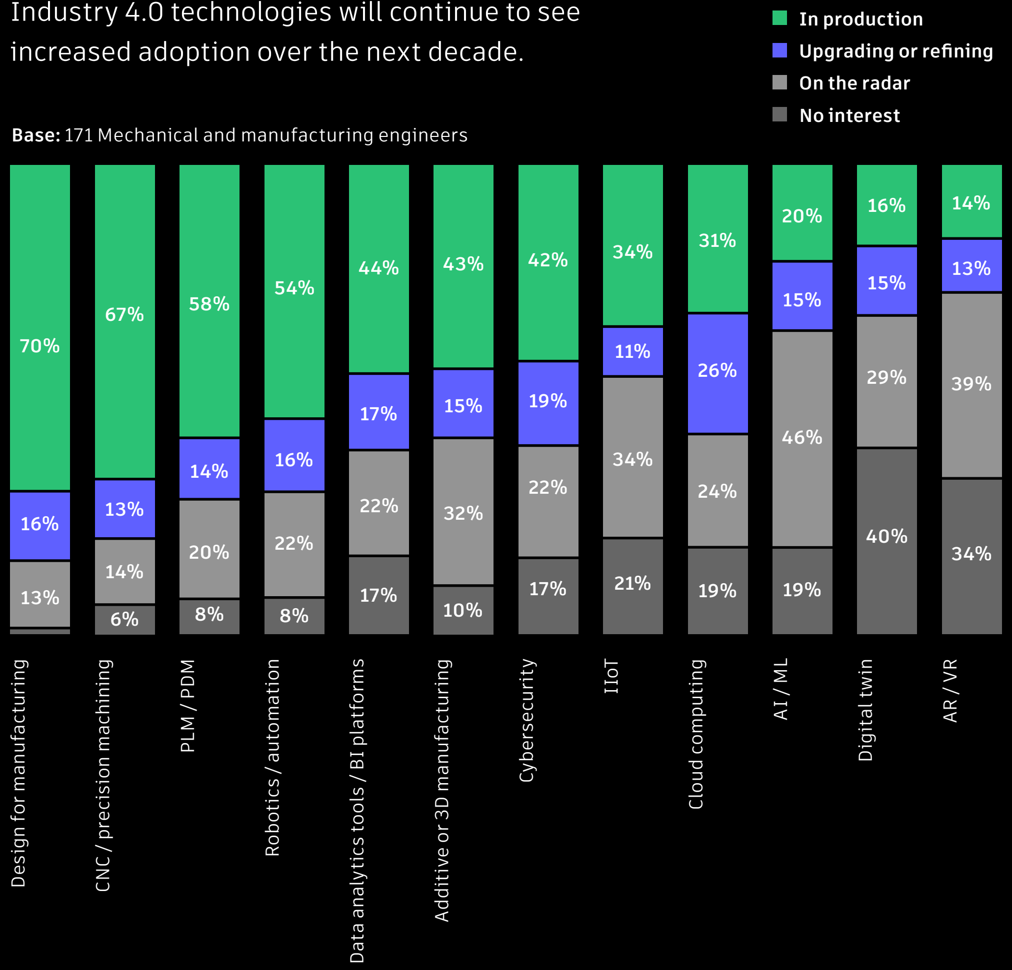
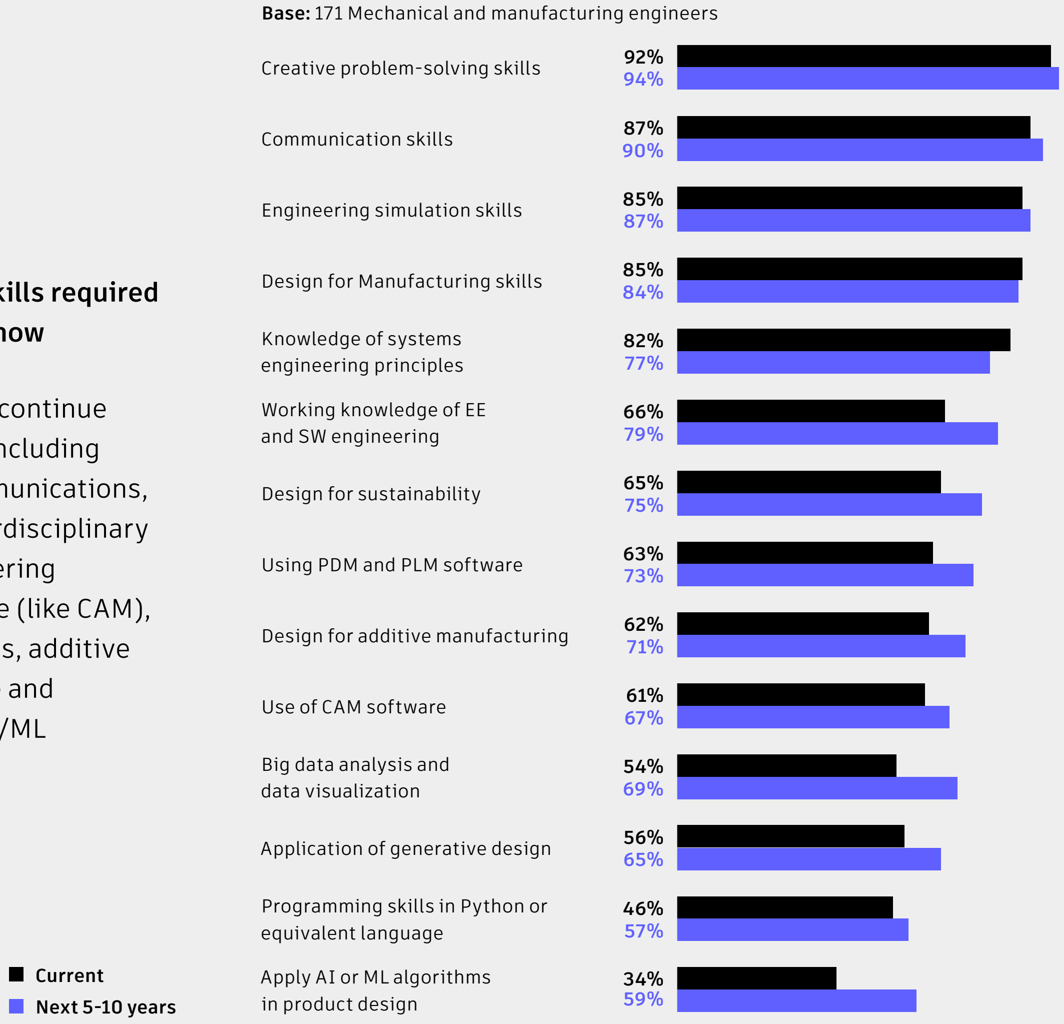


Figure 6:
Mechanical engineering skills required today vs. 5-10 years from now

Mechanical engineers will continue to need strong soft skills including problem-solving and communications, while expanding their interdisciplinary skills in EE and SW engineering knowledge, software usage (like CAM), programming, data analysis, additive manufacturing, generative and sustainable design, and AI/ML algorithm applications.



Manufacturing engineers today typically design, implement, and improve manufacturing processes and systems (see Figure 7). Most of them earned a bachelor's degree (76%), while a significant number hold an associate degree (16%) and others a high school diploma (4%).[6]

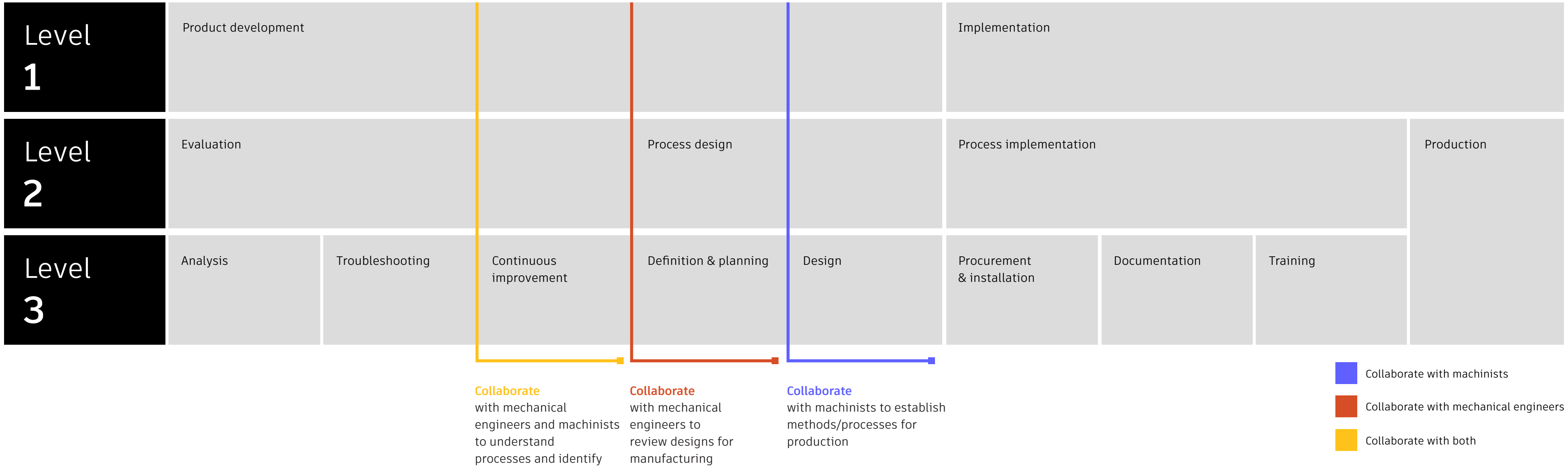
Current manufacturing engineer skills and technologies used:

- Machine tools and hardware
- Lean manufacturing
- Process improvement
- Quality control (QC)
- Computer aided design (CAD)
- Analytical software such as Matlab and Minitab

6 O*Net, "Manufacturing Engineers 17-2112.03," https://www.onetonline.org/link/summary/17-2112.03

Figure 7:
Current manufacturing engineer workflow

Note: See Appendix B for future connected workflow diagram and key collaboration points enabled by new technologies and tools.



Manufacturing engineers in 5-10 years will lead the strategic efforts to improve and adopt advanced manufacturing techniques and processes. They will determine how to apply technologies like AI/ML to improve automation results and adopt smart manufacturing practices like programming production lines, managing distributed manufacturing locations, and deploying real-time production monitoring systems. They will need to design and implement manufacturing systems to improve time-to-market and reduce cost, waste, and defects at the same time. This role will strive to find the right resource utilization across the human workforce and production machinery including robotics, additive manufacturing, and digital twins, using data analytics and visualization to find opportunities for efficiencies.

Over 70% of those surveyed believe hard skills like human-robot interaction will contribute to the dramatic shift in the manufacturing engineer role. Additional majorities pointed to skills in AI/ML for factory floor productivity, additive/hybrid manufacturing, and more robust operations technology (OT), including cloud storage, edge computing, MES/ERP platforms, cybersecurity, and the Internet of Things (IoT). AI and IoT can impact process optimization by running simulations for troubleshooting and equipment performance, resulting in continuous operational improvements.

A large majority of the engineers surveyed (88%) also see manufacturing engineers needing better design-for-manufacturing skills over the next 5-10 years, as well as real-time shop floor inspection (58%). UK respondents (n. 107) expect manufacturing engineers to increasingly adopt AR/VR (augmented reality/virtual reality) tools and techniques (65%).

Like all three of these manufacturing roles, manufacturing engineers will benefit from improved soft skills like problem solving, communication, and collaboration. Majorities of our survey takers believe mechanical engineers, manufacturing engineers, and machinists will collaborate with each other increasingly over the next 5-10 years. And North American engineers surveyed foresee greater collaboration between designers and machinists (68%), as well as QA/QC specialists (62%) (See figure 8.)

The manufacturing engineer position will become more interdisciplinary as it blends skills with both mechanical engineers and CNC machinists. As a result, they will need greater facility for integrating robotics and CNC machines, CAD/CAM software, and better data analytics. And 74% of industry respondents see a crucial role for manufacturing engineers focused on increasing factory line automation from machines, robots, sensors, and actuators.

> “In the future, the design software will be able to consider manufacturing constraints and also perform more accurate manufacturing process simulation, reducing the difference in the work between a design engineer and a manufacturing engineer, and mitigating the risk of designs being thrown over the wall that can’t be manufactured.”

Andrew Partin
Innovation Engineer
Stallantis

Future manufacturing engineers skills needed

Hard skills

- DfM
- AI/ML for factory floor productivity
- Robotics/cobotics
- CAD/CAM software and programming
- Additive and hybrid manufacturing
- Data analytics
- OT, including cloud storage, edge computing, cybersecurity, MES/ERP platforms, and the Internet of Things (IoT)
- CNC machining
- AR/VR

Soft skills

- Creative problem-solving
- Collaboration as individuals/teams
- Communications (written/verbal)

Interdisciplinary skills

- Mechanical engineering fundamentals
- Factory line automation from machines, robots, sensors, and actuators
- A focus on sustainability

Figure 8:
Manufacturing engineering skills required today vs. 5-10 years from now

Similar to mechanical engineers, tomorrow's manufacturing engineers will continue to need enhanced communication skills and manufacturing systems and QA/QC knowledge. They will also be expected to develop skills in data analysis, additive manufacturing (3D printing), digital twin, programming, and AI/ML applications to improve manufacturing throughput and efficiencies.

Base: 171 Mechanical and manufacturing engineers

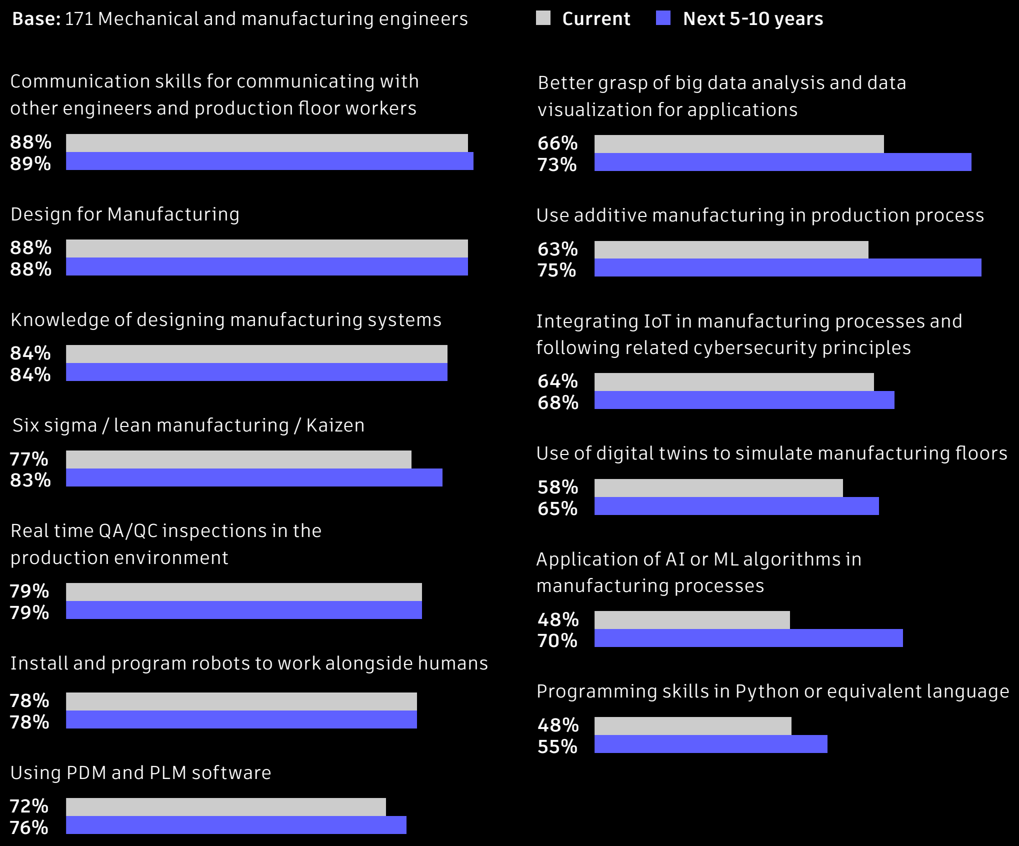
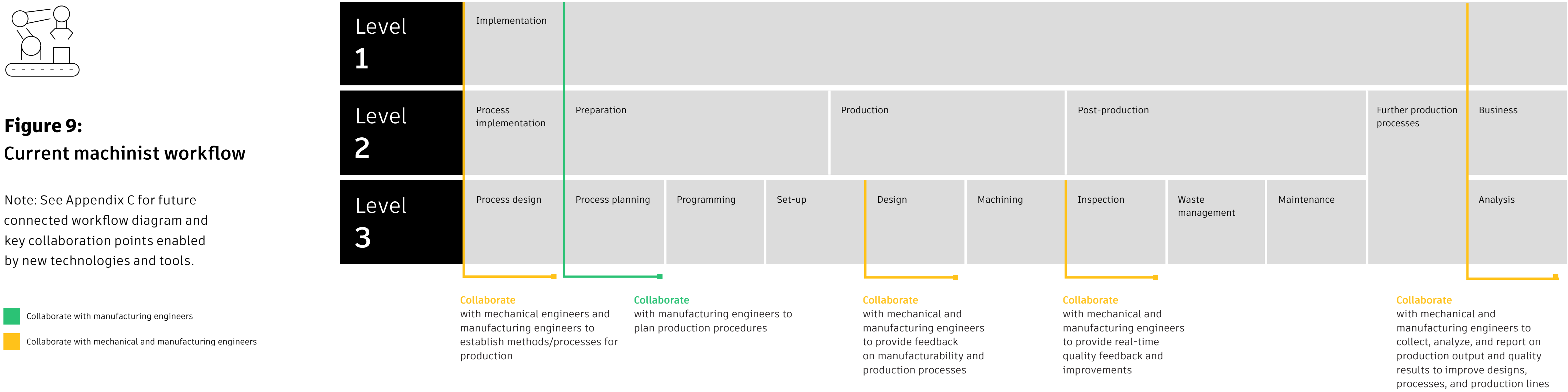


Figure 9: Current machinist workflow

Note: See Appendix C for future connected workflow diagram and key collaboration points enabled by new technologies and tools.



CNC machinists today are responsible for producing precision components using machining equipment and tools, as well as equipment setup, operation, repair, and maintenance (see figure 9). These professionals have a high school diploma or equivalent (36%), post-secondary certificates (33%), or some college credits without a degree (17%).[7]

Current CNC machinist skills and technologies used:

- CNC machining
- Workholding, machine kinematics, and geometric dimensioning and tolerancing (GD&T)
- CAD and CAM software for designing fixtures and tools
- A thorough understanding of machine tools and other hardware they use
- Working knowledge of ERP
- Analytical and industrial control software

7 O*Net, "Machinists 51-4041.00," https://www.onetonline.org/link/summary/51-4041.00

CNC machinists in 5-10 years will take the biggest step forward among the three positions as their role is significantly enhanced with Industry 4.0 technologies. Their position will expand and shift to include managing and programming robots and cobots, analyzing real-time production output, shop-floor inspection, and participating in quality assurance (QA) and quality control (QC). Machinists will need to develop new skills in AI/ML for production, five-axis machines, additive manufacturing, and hybrid manufacturing. They are also expected to collaborate more with engineering teams and be more involved with the upstream processes like design, which will require greater knowledge of CAD/CAM software. Over the next 5-10 years, industry professionals state the top CNC machinist hard skills required will be CAM software (86%) and CAD software (82%).

Becoming increasingly fluent in CAD/CAM software and programming, industry professionals assert, will enable machinists to increase their use of technologies, including five-axis machines (65%), additive/hybrid manufacturing (66%), and robotics/cobotics interaction (65%). While robotics is not very prevalent in today's CNC machinist work, they will need to integrate robotics into workflows and troubleshooting, while maintaining a sound fundamental knowledge of core machining principles. In the near future, CNC machinists must be able to utilize 3D CAD/CAM software tools with built-in GD&T capabilities and apply programming techniques to operate and maintain CNC machine fleets. In fact, 62% of surveyed industry engineers believe CNC machinists will need additional programming skills to program smart products over the next 5-10 years (see figure 10).

> "CNC machines are going to print all kinds of different materials. There's going to be an explosion in the different types of materials everybody's using. They're going to have to know how to work with all kinds of funky steel, aluminum, titanium, and lithium."

Pierre Larochelle, PhD
Department Head and Professor
South Dakota Mines

In general, CNC machinists must maintain and grow their mechanical know-how, but need to add more modern digital technology and software programming capabilities to impact production output and QC.

There is also widespread agreement—79% of all those surveyed—that more interdisciplinary collaboration among engineers and CNC machinists is necessary for a system-level purview of product development. Cooperation is needed to properly steward data from the growing number of smart factories (both large and small) implementing IoT devices, additive manufacturing, AI/ML, and advanced data analytics.

Future CNC machinist skills needed

Hard skills

AI/ML for production

Predictive/preventative maintenance

Additive and hybrid manufacturing

Robotics/cobotics interaction, programming, and/or maintenance

CAD/CAM software and programming

Five-axis or higher machines

Soft skills

Creative problem-solving

Collaboration as individuals/teams

Communications (written/verbal)

Interdisciplinary skills

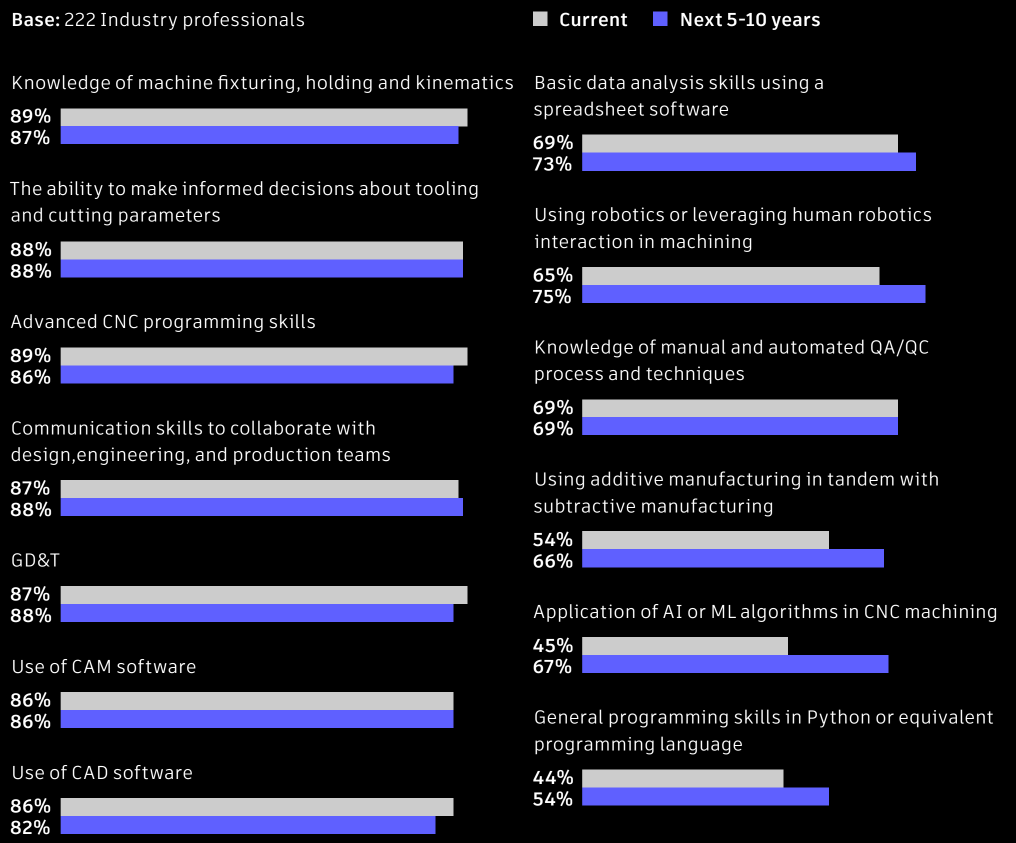
Working with engineers on product development

Working with QA and QC teams

Figure 10:
CNC machinist skills required today vs. 5-10 years from now

Many CNC machinist current skills will continue to be important. At the same time, they will be expected to have an increasing focus on human/robotics interaction, using additive and subtractive manufacturing in tandem (hybrid manufacturing), applying AI/ML algorithms, data analysis, and general programming skills.

Base: 222 Industry professionals

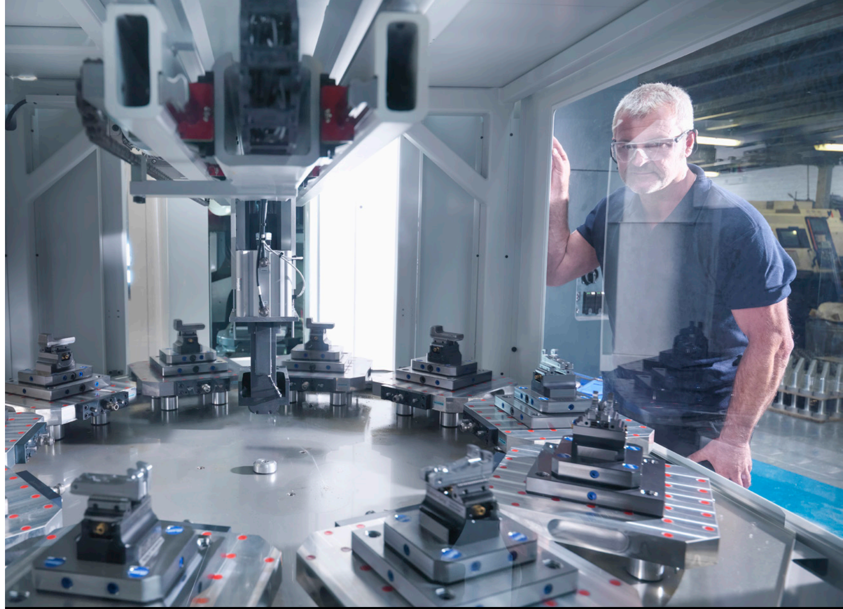


As business drivers move manufacturing further into Industry 4.0, mechanical engineers, manufacturing engineers, and machinists will need more advanced technological knowledge, not all of which can be attained from on-the-job reskilling. Industry is education's end user, so manufacturing education must align with Industry 4.0 trends to prepare students properly. Where education transition is not already underway, it is imperative for it to begin now.

At the same time, the manufacturing industry cannot simply pile new skills requirements onto these three occupations and expect to meet its business outcomes. As mechanical engineers, manufacturing engineers, and CNC machinists all become more ingrained in Industry 4.0 technologies, there needs to be a fundamental shift that redesigns workflows and the operational infrastructure so that every layer in the solution stack is centralized, connected, and integrated to all work together.

Far from being simply nice skills to have, the reconstructed roles and skill sets of mechanical engineers, manufacturing engineers, and CNC machinists are all necessary to achieve the desired business outcomes that are driving manufacturing into Industry 4.0. Because the current engineering education infrastructure does not produce the engineer of the near future, adding these new skill sets to the workforce requires businesses to embrace the concept of life-long learning to maintain a robust workforce ready for the latest innovations.

Fortunately, 86% of academics in our survey welcome a lower reliance on degrees and an emphasis on more specialized certifications developed in partnership with industry. Continued partnerships between industry and academia can help develop and maintain the Industry 4.0 workforce needed to achieve the competitive advantages of enhanced productivity, faster time-to-market, and overall profitability.



> "Ten years from now, a machinist will be what a manufacturing engineer is today, and a manufacturing engineer ten years from now will be a person that doesn't even exist today."

Timothy Robertson
ATDM Technical Program Manager
Institute for Advanced Learning and Research

Industry adoption guidelines

Some of the present realities outlined in this paper may appear fairly grim: a design and manufacturing field based largely on decades-old Industry 2.0/3.0 operations and an educational system that is not yet up to speed on endowing students with desperately needed Industry 4.0 skills.

However, there is plenty of silver lining to this situation. The Industry 4.0 technologies and workflows needed to achieve the business outcomes companies desire are here, and they are already established in some cases. To take advantage of them, businesses do not need to try to make the leap overnight. The path to a more efficient, sustainable, and profitable future within Industry 4.0 begins with a first step and can proceed incrementally from there. Only the companies that resist starting that step-by-step journey in the near-term risk being left permanently behind. Embracing the change now will put firms at an advantage and on the trajectory to positive outcomes for productivity, output, time-to-market, cost effectiveness, and sustainability.

A three-phase industry adoption path will guide organizations to fully adopt Industry 4.0 taking the system-level approach outlined above. The first phase is a digital transformation to adopt the foundational and enabling technologies to support and facilitate new workflows and business processes. The second phase is the workflow transformation where work is redefined to leverage the technical capabilities delivered in the digital transformation. The final third phase is the business process transformation where new technologies and workflows come together to achieve better business outcomes.

Transformation	Digital			Workflow	Business
Solution layer	Application	Infrastructure	Data	Workflow	Process
Goal	Consolidate and integrate applications and tools to converge workflows	Connect teams and systems to access and exchange data and files	Collect and organize all data on a single, centralized data management platform	Redefine roles, functions, and work interactions to take advantage of new data insights, technologies, and capabilities	Adopt new technologies and methodologies to increase productivity across the design and manufacturing process
Benefit	Reduce applications and simplify work using common software platforms	Link team members to interact better across functions and locations	Enable access by team members to make more informed work decisions	Collaborate more across roles and teams to coordinate and streamline workflows	Achieve better business outcomes through process improvements

A complete Industry 4.0 transformation converges all workforce roles so that everyone works together across disciplines in a collaborative effort using centralized, shared data, and information updated across all devices in real time. Both human and machine workflows are connected. Technologies such as generative design, other AI/ML processes, additive and hybrid manufacturing, cobotics, data visualization, and others are fully exploited for production.

This system-level transformation is inherently more efficient, but also opens the door to creative design and manufacturing improvements that unlock greater efficiencies, supply chain capacity, new profit centers, circular product lifecycles, and a host of other opportunities.

Academic adoption guidelines

Whether it is a mechanical engineering or manufacturing engineering degree program or a vocational CNC machining program, institutions and professors want to use industry-leading tools and technologies to teach their students. However, the real-world industry job requirements for those graduates are evolving faster and expanding beyond the scope of the existing education and training programs. Much of the education is not aligned with the most up-to-date Industry 4.0 skills that industry needs today and will need even more in the near term.

As a result, many manufacturing firms need to invest and spend months of on-the-job retraining on new hires, siphoning valuable resources across the company. In some cases, companies may pair a recent graduate with an existing engineer or machinist, effectively paying two people for doing a job that one fully trained person could do.

But as with manufacturers transitioning to Industry 4.0, the bigger the problem for academia, the greater the opportunity for transformation. Manufacturing education must take a comprehensive view of the industry needs to define the educational programs required. Academia cannot simply update its existing curriculum. It needs to adopt a new pedagogy to teach the advanced manufacturing knowledge, technologies, and skills required to succeed in industry. It starts by identifying the most urgent gaps and seeing those as opportunities to create new education and training programs.

According to the industry demand, mechanical engineering and manufacturing engineering programs represent the greatest opportunities to overhaul outdated curriculum. The ABET accreditation minimum standards will significantly influence the direction of these engineering programs, while community colleges and vocational schools have the most curriculum flexibility for creating new programs. That said, reimagining manufacturing training should come with a corresponding review of accreditation standards to allow for flexibility across education sectors.

Certainly, there will need to be alternatives to two-year and four-year programs, and fortunately, both industry and academia are on board with pursuing those alternatives. For example, 84% of all our survey respondents—both industry and academic—believe manufacturing employers and academia should partner on new types of certification programs based on employer needs, and 91% want new opportunities for long-term internships and co-op programs.

Below are suggestions to support academic institutions' efforts to prepare for the changes in workflows, technologies, and skills:

Education peers
Attend conferences and webinars to explore curricular evolution and discover best practices from the leading and most innovative institutions

Industry faculty
Invite active industry experts and practitioners into classes to share real-world experiences, insights, and learnings

Industry partnerships
Learn the emerging technologies and skills trends from industry thought leaders and advisory boards to help shape new educational and training programs

Technology companies
Leverage existing online and in-person educational resources from manufacturing hardware and software companies to learn the latest innovations and solutions deployed in industry

Continuing education programs
Create flexible university and community college programs for working adults to learn necessary new skills and address gaps that may not be covered in core curricula

Academic evolution can take place in four stages:

Stage 1
Reimagine training from the bottom up to align with the digital transformation of current and future workflows based on Industry 4.0 technologies. Look for opportunities to replace theory-based knowledge with applied learning.

Stage 2
Engage industry and technology partners to establish an industry/academia relationship to stay current on industry trends, developments, and required skills to prepare students for the workforce.

Stage 3
Realign current curriculum and/or create new curricula or programs to teach advanced manufacturing subjects and skills—requested by industry—that will support the new workflows and business processes.

Stage 4
Maintain an open dialog with industry and regularly review curriculum and programs to ensure industry alignment.

Collaboration between industry, academia & government

Government, industry, and academia all must take part in creating tomorrow's manufacturing workforce. Of the 324 surveyed, both industry and academic respondents believe industry can contribute to the manufacturing workforce of the future through internships and co-op programs (90%), robust internal training and development (86%), and partnering with and supporting local colleges and community colleges (74%).

Of 102 academics surveyed, most would like to see industry executives deployed as faculty (80%), as well as direct financial support (87%). Two-thirds of engineers see promise in promoting advanced manufacturing careers to secondary school students. Engineering academics know they must incorporate more practical, "hands-on" learning opportunities for students to fully grasp design for manufacturing knowledge and skills (90%). (See figure 11). We are seeing more collaboration among academic institutions—such as universities partnering with community colleges—to rethink engineering education from the ground up. Academia also leans toward adding more specialized certifications (86%) and including subjects that promote critical thinking and communication (81%).

Industry professionals (51%) suggest instead that engineering programs add another year to teach future advanced manufacturing skills. However, there is notable disagreement with the presumptions that engineering education should develop "generalists" rather than "specialists" or that engineering degrees are losing their importance (see figure 11).

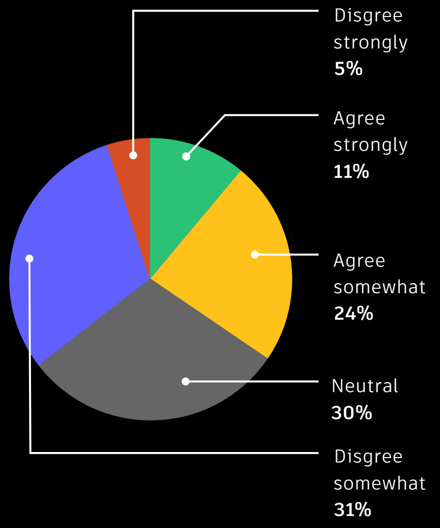
Figure 11:
Attitudes about education and the future of manufacturing

There is notable disagreement with the presumptions that engineering education should develop "generalists" rather than "specialists" or that engineering degrees are losing their importance.

Base: 324 all respondents)

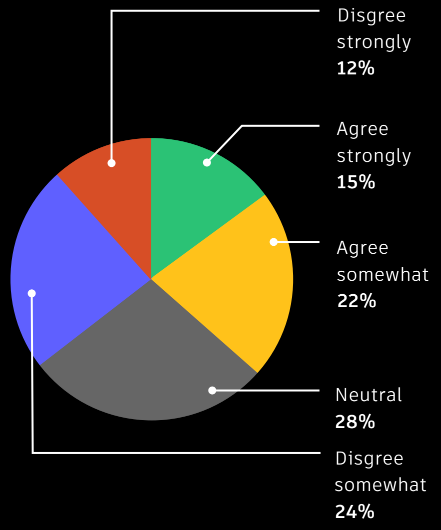
Total agree
35%

We should be developing more engineering "generalists" rather than focusing on "specialists"



Total agree
37%

Engineering degrees are becoming less and certifications more important to employers



Role of industry

To prepare students and current employees for future work assignments, industry must understand and embrace continuing education and training. It should also practice internal training programs, as well as regular job and project rotations to expose workers to a range of cross-functional disciplines (see figure 12).

Working shoulder-to-shoulder with academic institutions, industry can clearly articulate its needs and provide longer-term student internship opportunities. Active industry executives and other professionals can also grant essential expertise by sitting on college advisory boards and teaching as part-time faculty.

By reaching young people at earlier ages, industry can demonstrate that manufacturing is high-tech, concerned with sustainability, and an overall worthy career path. It can take more control over its labor force destiny by showing that advanced manufacturing is no longer the outmoded visions of dark factories, smokestacks, and an aging workforce.

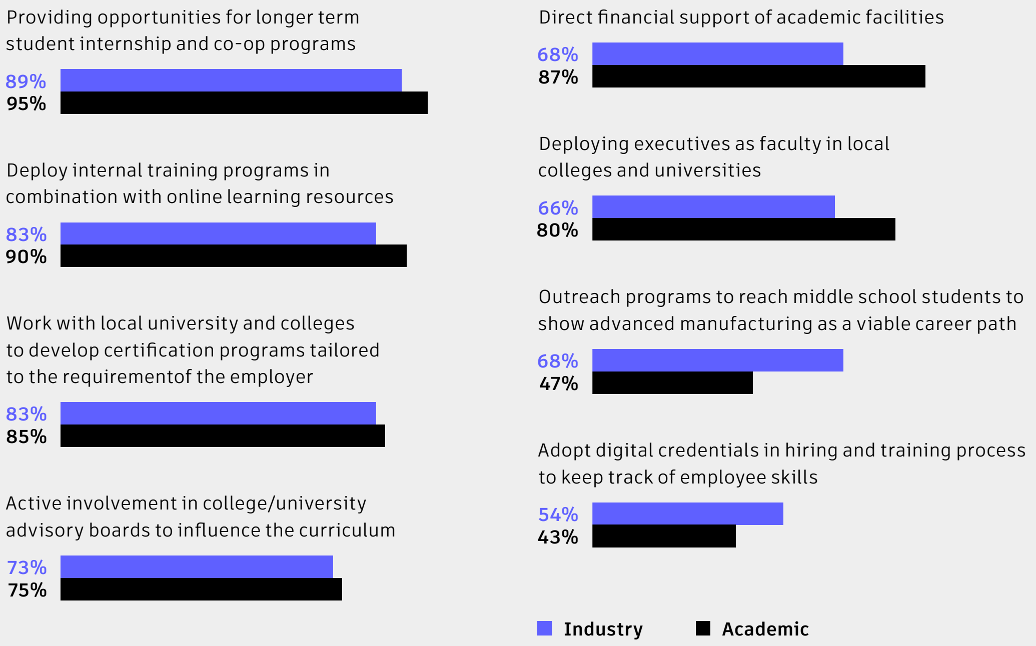
> "It's important for the entry-level workforce to be exposed to a variety of processes. Ideally, employers would afford them the opportunity to rotate through electronics and mechanical work, hydraulics and pneumatics, and manufacturing support."

John Saunders
Principal, Saunders Machine Works

Figure 12:
Most effective strategic initiatives by industry to develop the manufacturing workforce of the future

Industry can contribute further by lengthening internships and co-op programs, developing certification programs with local universities and colleges, and increasing support to universities, community colleges, and primary/secondary schools.

Base: 222 Industry professionals and 102 academic professionals



Role of academia

Manufacturing and engineering education needs an overhaul to “reduce the time to talent.” While there will still be a need for specialization and research, swifter alternatives are needed to produce application-centered professionals. The movement is afoot to refocus manufacturing education toward a real-world, hands-on, project-based pedagogy. However, academics are reluctant to abandon engineering fundamentals like math and science. Engineering education must become more interdisciplinary while also avoiding an overly generalized approach where students know a little of everything but without practical expertise in one area.

Employers and students will still demand engineering degrees related to manufacturing. However, other credentials—such as certifications for software, roles, or specific machines—will become more prevalent and accepted in this decade.

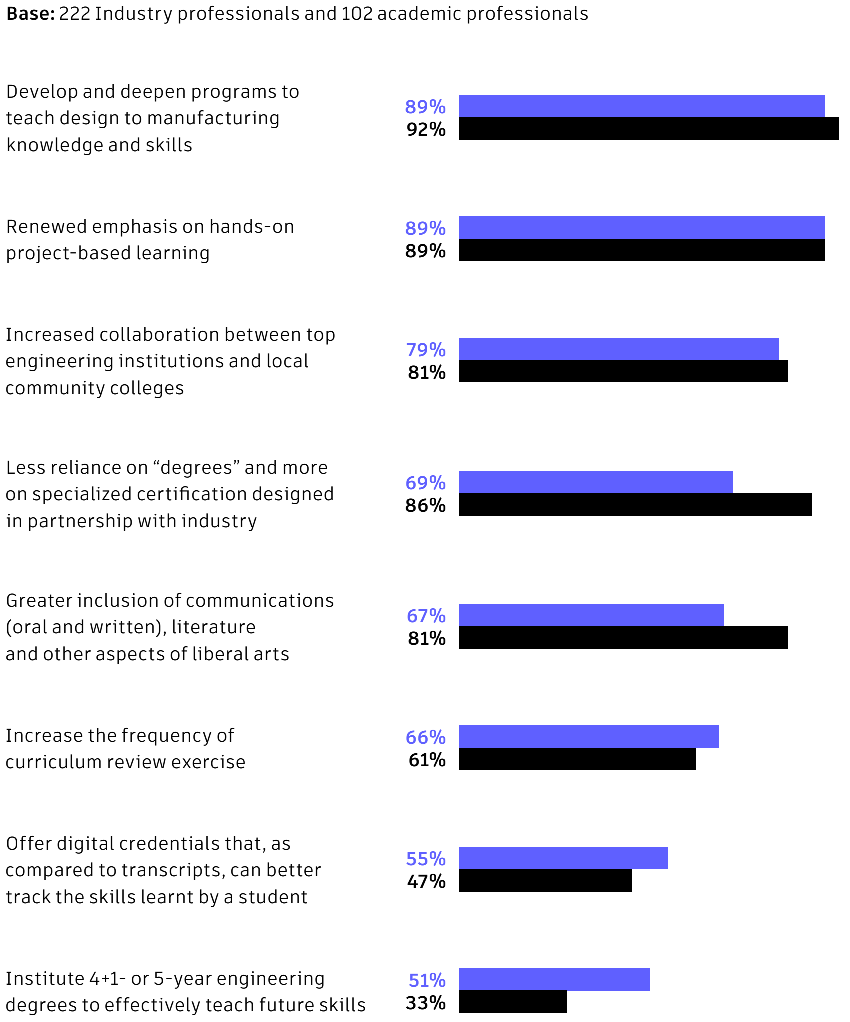
Some college engineering programs are recruiting faculty from current industry professionals to teach DfM skills to the next generation. Community colleges play a vital role (particularly by upskilling machinists and operators) because of their close connections to local businesses, as well as greater flexibility with curricula. Many community colleges partner with local universities to provide onramps to advanced manufacturing engineering programs for students with two-year Associate degrees.

With 82% support from all survey respondents, apprenticeships are a popular concept for the new manufacturing workforce (see figure 13). Rather than the European apprenticeship model, an academic/industry apprenticeship partnership with government oversight for funding, regulations, and standards is on the table. Likewise, 91% see longer-term internships and co-op programs in collaboration with industry and academia as an effective option.

A larger number of industry representatives (51% versus 33% in academia) suggests keeping engineering students in school for an extra year to teach Industry 4.0 skills, similar to what is practiced in Europe. However, students and families would have to shoulder additional financial burdens unless industry, universities, or government subsidized the extra year. That approach would also keep trainees in school even longer, whereas the manufacturing sector faces a skills gap and a shortage of qualified candidates now.

Figure 13:
Most effective strategic initiatives by academia to develop the manufacturing workforce of the future

Academics tend to favor more specialized certifications as well as more subjects that promote critical thinking and communication. Industry professionals suggest engineering programs add another year to teach advanced manufacturing skills.



"We need to go one step further with real-world examples. If we create an environment where students look at problems from a project-based approach in a complex real-world context, then that will enable them to see and connect the dots."

Raju Dandu, PhD
Professor; Director, Bulk Solids Innovation Center
Kansas State University Salina

Role of government

Government agencies can also play active roles in developing the advanced manufacturing workforce. Among all 324 survey respondents, government funded scholarships for engineering and machinist training were the most popular option (86%) for government assistance (see figure 14). Engineering faculty want government grants for next-generation manufacturing equipment in schools at a rate of 89% versus 80% of industry respondents. Academics also favor government collaboration for defining and funding standardized apprenticeships by 88% compared to 79% from industry.

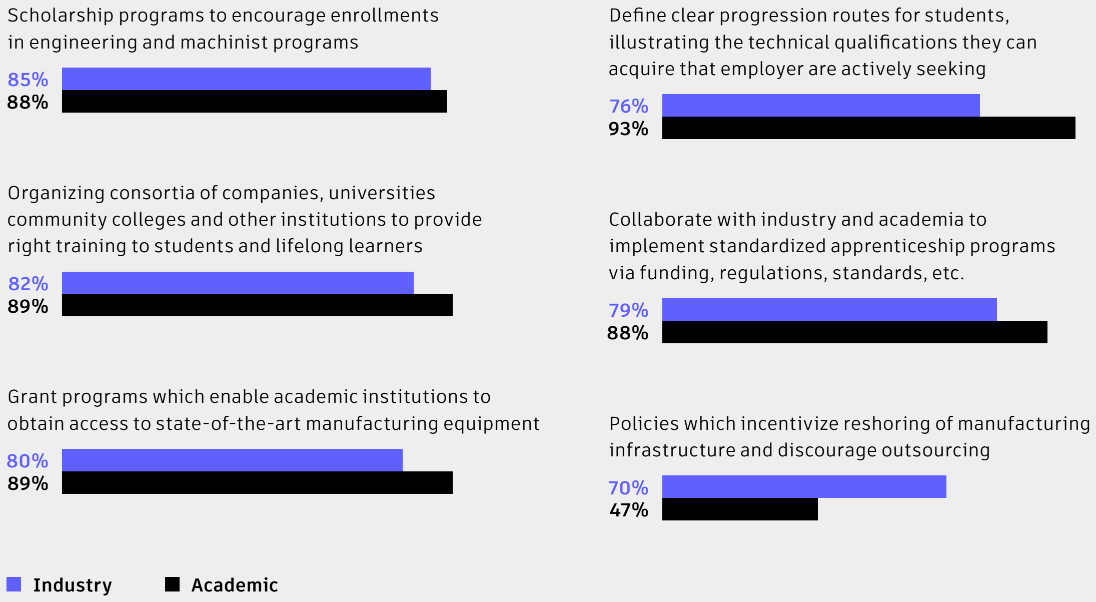
Within public-private partnerships, federal, state, and local government agencies can aid workforce upskilling by:

- Providing financial assistance to universities and research consortia
- Encouraging educational/private sector collaboration
- Advocating for and advancing the development of new multi-institutional training methods

Figure 14:
Most effective strategic initiatives by government to develop the manufacturing workforce of the future

Engineering faculty are eager for government help building the manufacturing workforce through grant programs, codifying clearly defined technical qualifications, and fostering active collaboration between government, industry, and academia.

Base: 222 Industry professionals and 102 academic professionals

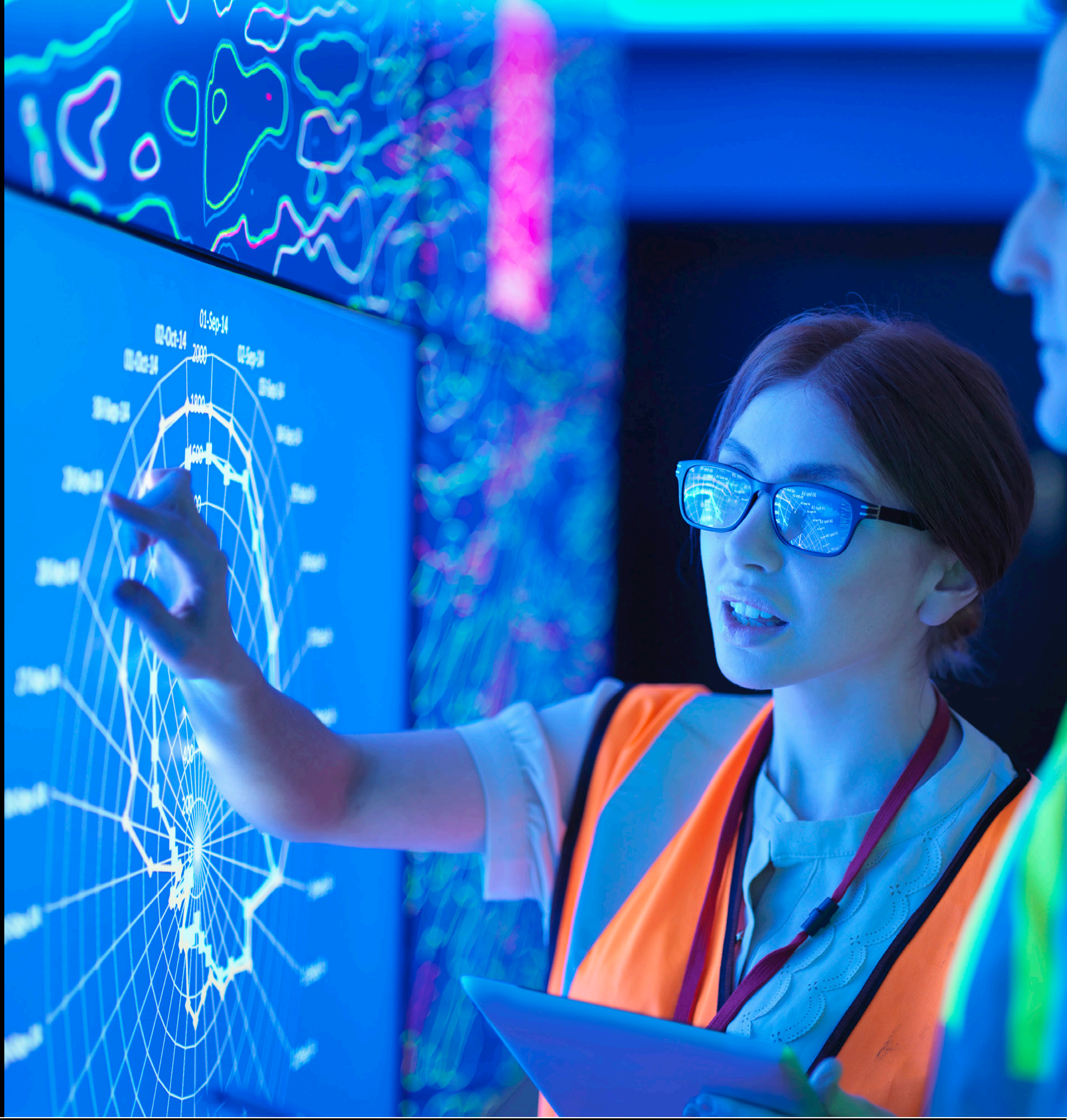


Conclusion

Naturally, every manufacturing business wants to build a better system that generates improved productivity, profits, sustainability, and competitive advantage. The path to those results inevitably leads manufacturers to Industry 4.0 technologies, and that transition is well underway.

Their digital transformation journey will identify the Industry 4.0 technologies to support and enable reengineered manufacturing business processes and workflows. The adoption of new technologies like AI/ML, cloud-based software platforms, digital and operational technology infrastructure, robotics/cobotics, additive/hybrid manufacturing, performance monitoring and data analytics, along with the new workflows, will lead to a more connected, collaborative, and continuous manufacturing system.

That in turn will determine the educational and training requirements needed to support the new system-level changes across the workforce. With a reimagined manufacturing education ecosystem, engineers and machinists will be able to obtain the knowledge, training, and skills development to harness new technologies and tools to succeed in the workforce. By working together to understand global trends and industry needs, government, academia, and industry stakeholders can enable the next generation of mechanical engineers, manufacturing engineers, and CNC machinists with the skills needed to complete the greatest shift in manufacturing history.



This transition will change the emphasis and scope of responsibilities and skills needed for mechanical engineers, manufacturing engineers, and CNC machinists. It is critical to deliver new hard and soft skills training to new students and current employees to realize the value of the digital transformation.

However, today's predominant manufacturing education methods and curricula will not be sufficient to prepare students with the necessary skills. Like the manufacturing industry, education must embark on its own transformation to develop a pedagogy for teaching the necessary knowledge and skills.

This transformation is possible with cooperation between academia, industry, and government to evolve manufacturing training by:

- Reimagining training to align current workflows with the future workflows of Industry 4.0
- Realigning the curriculum based on the skills those workflows require
- Partnering industry and tech companies with academia to create curricula and keep up with industry trends and technology education needs
- Maintaining a dialog with industry to regularly review curriculum and programs that align with industry needs

The future of manufacturing is evolving and changing. Industry 4.0 will not be the final technology destination along this journey. However, it is a critical and necessary step in the right direction to achieve the business outcomes needed. Innovative firms will continue to find new ways to drive efficiency, profitability, and sustainability long after they have made the transition to Industry 4.0. They will continue to add new technology building blocks and refine workflows to support their future in manufacturing. And the industry will need education to prepare the future workforce to design and manufacture the future.

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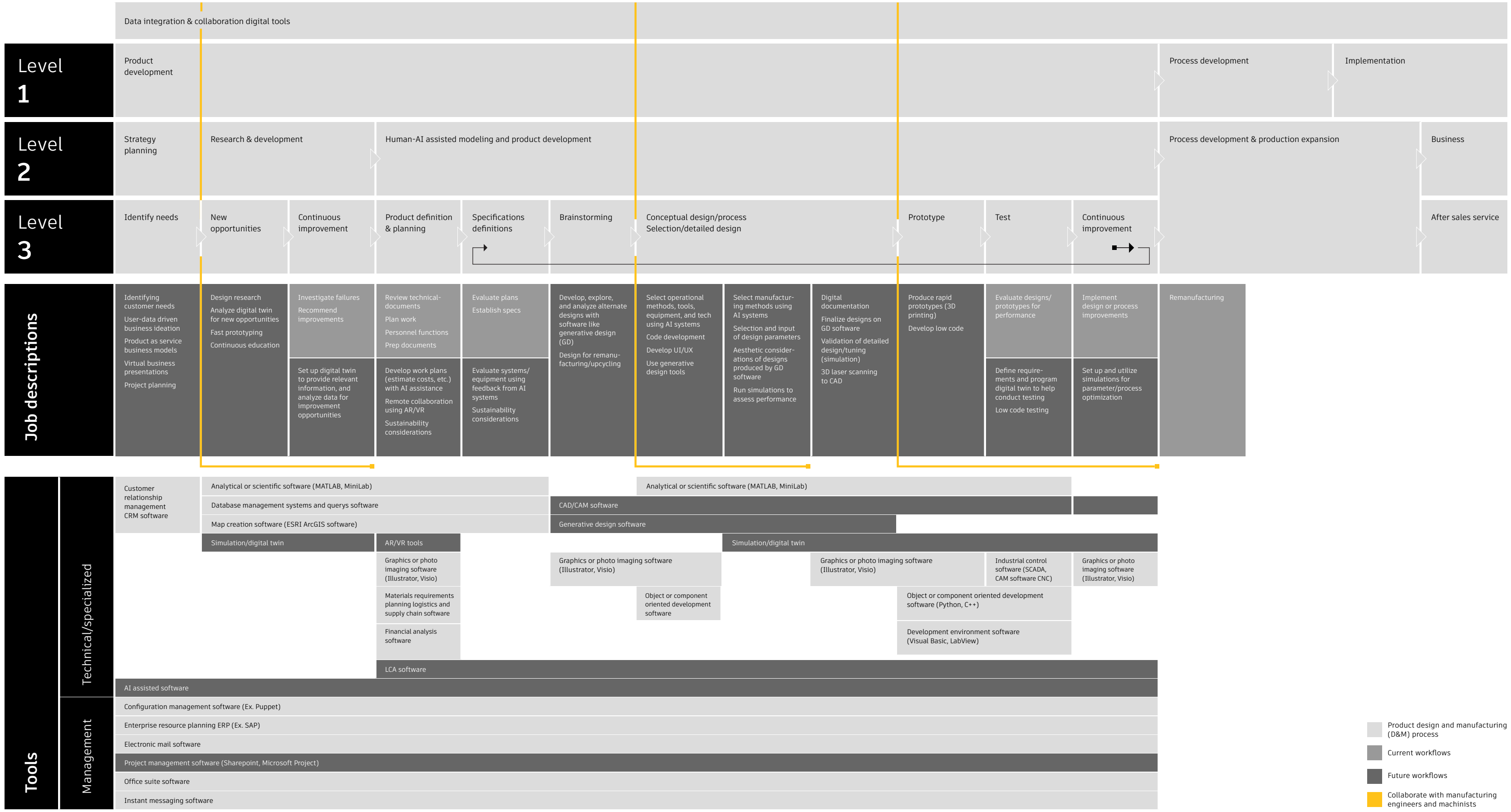
Limitations of the study

This study is based on published reports, semi-structured interviews, and a survey of select experts. This study is for informational and educational purposes only. Autodesk, ASME, and the authors disclaim all responsibility or liability for any loss or damage resulting to any person or entity acting or refraining to take action based on any material included in this publication.

Appendix A

Mechanical engineer: Comparison of current and future workflows

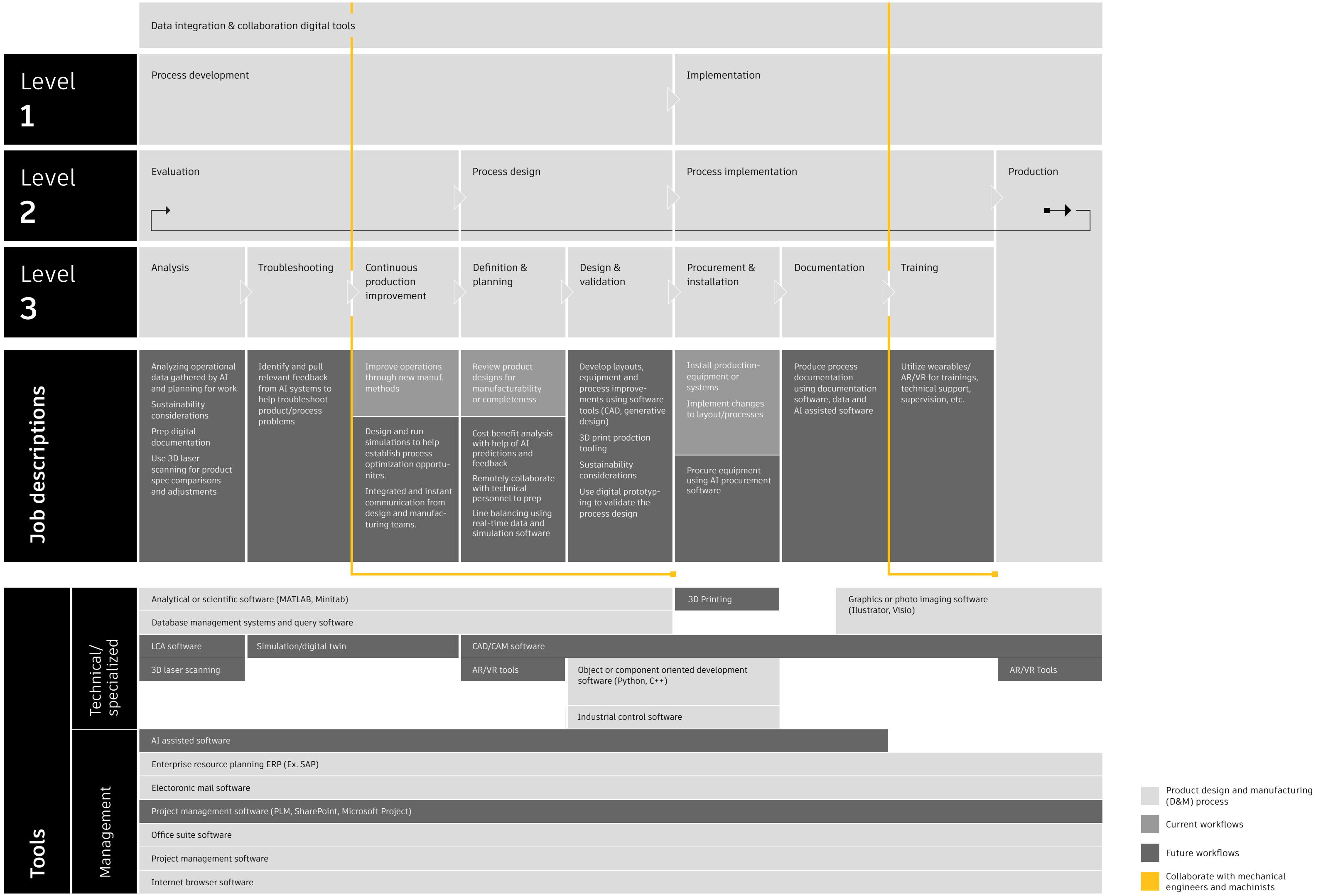
Note:
Future-state workflows will require similar steps as current-state workflows; however, the velocity at which they are achieved will be greatly accelerated through converged platforms, connected workflows, and cross-functional collaboration.



Appendix B

Manufacturing engineer: Comparison of current and future workflows

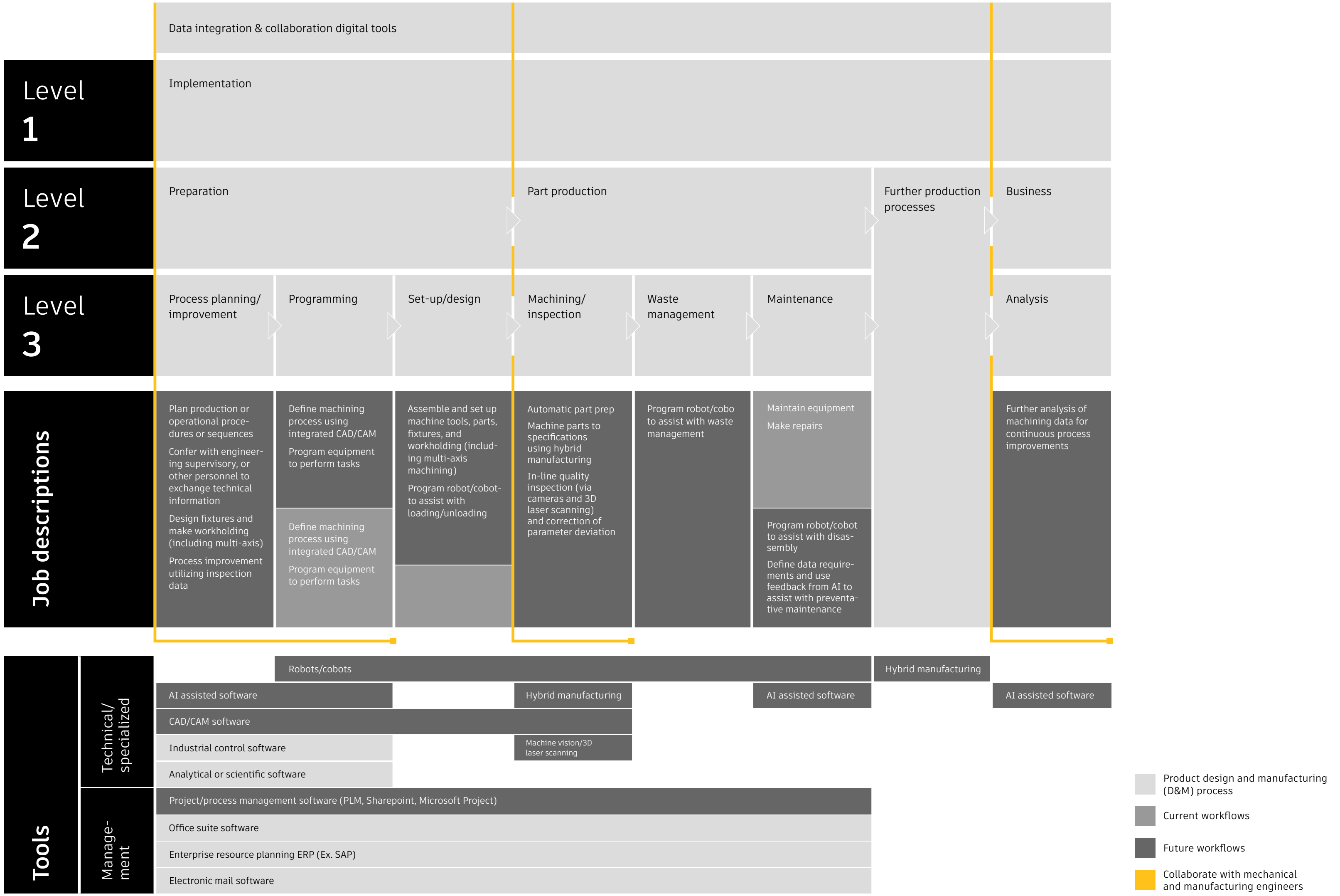
Note:
Future-state workflows will require similar steps as current-state workflows; however, the velocity at which they are achieved will be greatly accelerated through converged platforms, connected workflows, and cross-functional collaboration.



Appendix C

Machinist:
Comparison of current and future workflows

Note:
Future-state workflows will require similar steps as current-state workflows; however, the velocity at which they are achieved will be greatly accelerated through converged platforms, connected workflows, and cross-functional collaboration.



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