

Preparing the Advanced Manufacturing Workforce: A Study of Occupation and Skills Demand in the Advanced Robotics Industry

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Cover image: Robotic arms along assembly line. Photo courtesy of the ARM Institute.

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Note: This report is a part of a Workforce Roadmap series that characterize technical workforce needs for advanced manufacturing areas focused on highly specialized training for jobs aligned with specific U.S. Manufacturing Institutes including integrated photonics, robotics, flexible electronics, functional fabrics, and 3D/additive manufacturing.

Executive Summary

Workforce needs were identified for middle skilled technical workers in the robotics industry through both semi-structured interviews with operations managers from thirty-one firms and analysis of real-time labor market intelligence databases. The interviews focused on middle-skilled technical occupations (except for information technology). The goal of the interviews was to characterize trends in demand, hiring challenges, training gaps, and the importance of specific technical and human skills to the robotics industry. Results demonstrate increasing demand for middle-skilled technical workers (See Figure ES 1) and highlight skills gaps among these workers.

There is strong growth expected for mechatronics technicians, electrical and mechanical engineering technicians, and robotics installation and deployment technicians (represented by the category Other technical production workers in the interview). Interestingly, of the occupations studied here, robotics deployment technicians are expected to see the largest growth in number of positions and openings within the United States robotics industry.

Training for technical workers in the advanced robotics for manufacturing industry should increase emphasis on:

- Providing consultation & advice to others
- Programming computers & equipment
- Monitoring processes, materials, or surroundings (testing and quality control)
- Troubleshooting, repairing and maintaining equipment
- Preparing specimens, tools, or equipment
- Communicating and collaborating with engineering and management staff
- Managing unfamiliar situations
- Independently organizing time & priorities

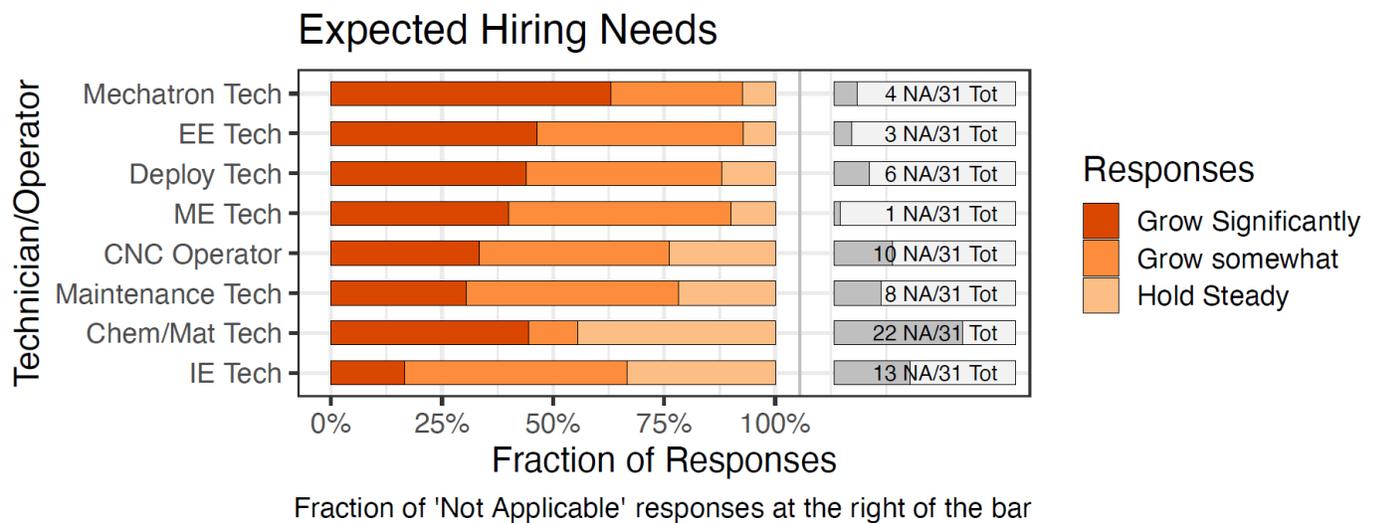


Figure ES 1 Survey results on future change in demand for the technical occupations evaluated in this study.

To further characterize workforce demand in this sector, we made use of data from the US Bureau of Labor Statistics, market intelligence reports, and survey responses to project both anticipated positions and openings. We estimate middle-skilled positions within this industry to grow from around 4,000 today to 7,500 by the end of the decade (see Figure ES 2. Survey results, data from the US Bureau of Labor Statistics, and market intelligence reports were used to project existing positions and expected openings for middle-skilled technical workers. (a) Shows an overview of trends. (b) Provides details by position.). This

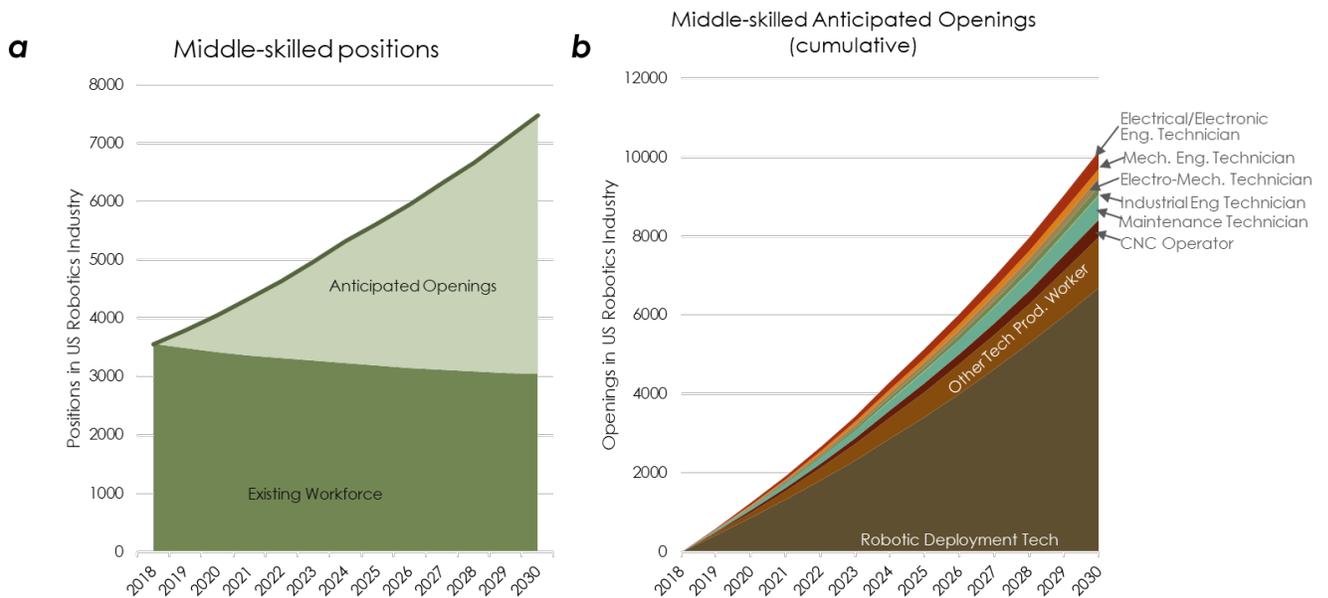


Figure ES 2. Survey results, data from the US Bureau of Labor Statistics, and market intelligence reports were used to project existing positions and expected openings for middle-skilled technical workers. (a) Shows an overview of trends. (b) Provides details by position.

growth means that more than 10,000 cumulative middle-skilled technical openings are expected this decade. This translates to 870 per year, excluding expected retirement and other separations. Assuming a typical training program graduates about 15 students per year, the US would need more than 60 programs to meet the demand of this industry. In a Massachusetts context, we estimate around 275 positions today growing to 470 positions in 2030. This translates to about 54 middle-skilled openings per year, resulting in about 4 programs needed for training middle-skilled workers in the state.

In addition to respondents indicating strong growth for many of the occupations, respondents also emphasized significant hiring challenges and a need for extensive on-the-job training for new hires especially for Mechatronics Technicians.

To better understand how to improve training, we explored the importance and skills gaps (difference between the skill level of new hires and that needed by industry) for five occupations: mechatronics technicians, electrical engineering technicians, mechanical engineering technicians, industrial engineering technicians, and CNC tool operators.

Emerging and human skill importance was also evaluated for each position including a critical thinking needs assessment. From this, we also learned that the following four human skills should be included in training for technicians in the robotics industry:

- Communicating and collaborating with engineering and management staff
 - Including the use of digital collaboration tools
- Managing unfamiliar problems and situations
- Independently organizing time or prioritizing skills



Figure ES 3 General Task/Skill (GTS) are classes that include many related specific skills. Here relevant GTS are ranked by weighted average importance of the specific skills within that class. Only GTS that are shared across at least two occupations are labeled as common and, therefore, included in this figure. Asterisks indicate skills that also have a critical gap and are of significant importance.

“What engineers were doing three years ago, technicians are now expected to do.”
New England Advanced Robotics for Manufacturing Company Representative, June 2021

Many firms indicated that critical thinking skills are becoming essential for engineering technician positions. Because technicians are a part of the front line, being able to think

critically and identify patterns of error is important. Results indicate that the majority of engineering technicians (68%) are expected to have competency in nearly all aspects of critical thinking (perceiving, hypothesizing, testing, and interpreting testing) and an additional 15% are also expected to communicate the outcome of the process.

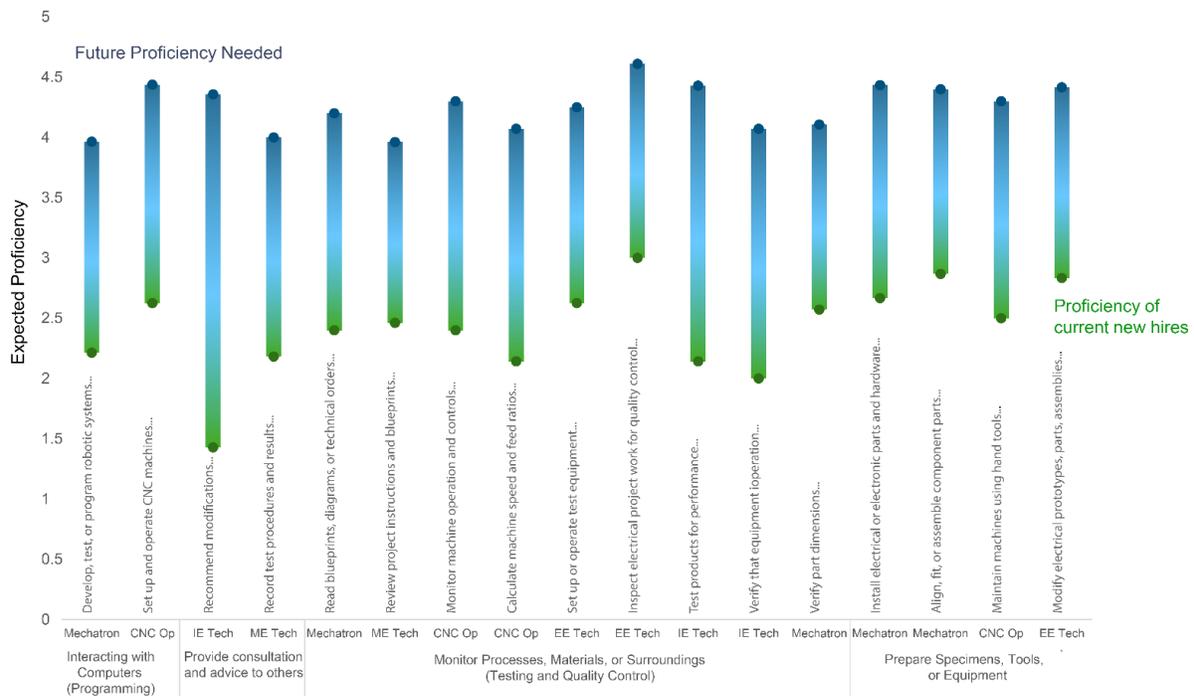


Figure ES 4 High priority skills across all positions studied in the robotics industry. The green dot represents the proficiency of current new hires and the blue dot represents the future proficiency needed for the middle-skilled level.

Because the interviews focused on skills derived from work activities described in the Bureau of Labor Statistics O*Net dataset, it was possible to not only identify job-specific skills but also to use the taxonomy within that dataset to aggregate survey responses to more generalized classes of skills (referred to as General Task/Skill, GTS). Figure ES 3 shows the result of that aggregation across all survey responses.

To get a better understanding of where training resources would be best applied, we also examined whether important skills also exhibited a significant skills gap (difference between competency of new hires and that required by industry). As shown in Figure ES 4, four of the most important GTS categories of skills were also frequently flagged as exhibiting a significant skills gap.

Based on this analysis which looks across all middle-skilled technical occupations in the robotics industry, there are five classes of skills that should receive increased emphasis within training programs. These are (asterisk indicates both high importance and significant observed skills gap):

- Provide Consultation and Advice to Others*
- Repairing and Maintaining Equipment*
- Prepare specimens, tools, or equipment
- Interacting with Computers*
- Monitor Processes, Materials, or Surroundings*

Based on these results, it is clear that it would be valuable to increase emphasis within engineering technician training on skills that aid technicians in providing consultation and advice to others. This includes both an understanding of the entire system or process as well as verbal and written communication skills to explain the details of the problem and potential solutions. Repairing and maintaining equipment entails building, calibrating, and troubleshooting equipment malfunctions to minimize downtime. Preparing specimens, tools, or equipment involves the ability to follow operating procedures and safety guidelines and attention to detail. Technicians in the robotics industry are also expected to interact with computers including programming computer and production systems and debugging code to resolve technical problems. In addition to the ability to repair equipment, the skill of monitoring processes, materials, or surrounding is also common across positions. This skill requires knowledge of quality, the ability to collect and interpret data on process or product, attention to detail, and knowledge of operating safety and settings.

For middle-skilled workers in the robotics industry, the analysis of generalized skills points to the growing importance of the abilities to program, operate, and troubleshoot equipment, to collect and interpret data, and to communicate that interpretation to others.

Taken together, these results demonstrate both the increasing number of technical careers in the robotics industry and the presence of key opportunities to improve the training and skills development of those pursuing these occupations.

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Workforce Roadmapping Report Series

Manufacturing – particularly advanced manufacturing¹ – is widely recognized as important for the United States for economic, strategic, and, more recently, public health benefits. Realizing those benefits will require both critical investments and intelligent policies. One challenge facing advanced manufacturing in the US that is less widely discussed is a mismatch between the supply of qualified employees and the needs of industrial employers.

In fact, 83% of manufacturers in the United States report a shortage of qualified employees (Huang et al. 2015). A recent study by Deloitte and the Manufacturing Institute estimates that this shortage may lead to as many as 2 million manufacturing jobs going unfilled over the next decade (Giffi et al. 2018). This structural unemployment has been attributed to both evolving manufacturing technology and to a declining interest in manufacturing jobs.

Furthermore, the emergence of new technologies can initiate new structures for knowledge coordination across formerly well-defined occupational boundaries. Technological changes can impact how worker tasks and therefore skills needs evolve and influence labor- demand effects and training as shown with automation and parts consolidation (Combemale et al. 2019). For example, the introduction of CT scanners changed the balance of knowledge between radiologists and technicians. Radiologists, less familiar with complex CT topics than they were to the simpler X-ray technology, evolved to a more collaborative approach to working with technicians (Barley 1986). Similarly, Frank Gehry's complex designs strained the modular boundary between architect and builder, with the separate roles collaborating much more closely in the design and building processes (Yoo, Boland, and Lyytinen 2006). These relationships can modularize again as technologies and knowledge become more mature, only to re-integrate as new technology or market concepts arise (Christensen, Verlinden, and Westerman 2002).

In a recent study, Combemale et al. (2021) find that new technologies are likely to lead to such workforce changes explicitly within the integrated photonics industry. Specifically, they find that changes in technologies for advanced manufacturing industries impact the distribution of demand for worker skills. Their study captures the labor-demand effects of technological changes in the automation of production processes and consolidation of parts using shop-floor data from various semiconductor firms. The O*NET database was used to identify skills and abilities² for each optoelectronic occupation for each process step. Results indicate that automation of production

¹ Advanced manufacturing includes both the application of new manufacturing processes and the production of innovative new products using either traditional or new processes.

² This study complements the work of Combemale et al. (2021) by focusing on O*NET work activities, detailed descriptions of worker tasks, rather than O*NET skills and abilities

processes would reduce the need for middle-skilled operators while conversely product integration would increase demand for middle-skilled workers. While these technical changes are not expected to reduce the number of jobs, they would be expected to change the portfolio of skills that are most valued. Furthermore, there is no reason that such trends would not carry over to other industries as they automate and develop more functionally integrated products.

In light of these needs and trends, this report aims to better characterize the evolving technical workforce needs within a specific advanced manufacturing sector – the robotics industry in the New England Region. We give particular focus to middle-skilled occupations³ within this industry.

As part of this characterization, we attempt to

- estimate the demand for middle workers by occupation type
- identify what occupations represent the most serious hiring and training challenges
- characterize critical skills gaps by quantify both what skills are most important for a given occupation and how well new hires tend to perform at those skills
- identify emerging skills within the industry
- evaluate the importance of specific human skills

An understanding of these issues within the current workforce can aid in informing education and training programs to prepare future advanced manufacturing workers.

To explore these questions, we develop and apply a new research method because traditional sources of information about labor needs are not well suited to answer questions about specialized sectors within advanced manufacturing.

The most widely consulted source of data on the US labor market is the Occupational Information Network (O*NET) database maintained by the Bureau of Labor Statistics (BLS)(U.S. Department of Labor 2020). That database contains information about workforce needs broken down into around 1000 occupation types across more than 100 industrial sectors. Although this serves as an invaluable source of information for workforce questions, there are at least two challenges to applying it to examine needs within advanced manufacturing. First, despite the scope and detail of the O*NET database, it is difficult to isolate the needs of emerging industries within that data. It will always be the case that advanced manufacturing sectors (examples of which today include photonics, robotics, and additive manufacturing) will operate at the interfaces of traditional sectors and as such will not be simply mapped using conventional industrial

³ Here we define middle-skilled workers as those with training beyond a high-school diploma, but short of a bachelor's degree. The terms middle-skilled worker and middle worker will be used synonymously. Middle-skilled occupations are those filled predominantly by middle-skilled workers. More formal definitions are provided in the methods section.

classification systems. Secondly, there will always be concern that government databases are not updated frequently enough to capture the trends within rapidly evolving industries.

Defining the Robotics Industry

Since George Charles Devol invented the first industrial robot, the Unimate, in 1954, robots have been used in industrial applications to improve overall production efficiency and quality (Malone 2011). Integrating robots in industrial applications can lead to impactful safety improvements, especially when the robot is assigned work that is especially dangerous or prone to causing human injury (NIOSH 2021). This also creates an opportunity for the human worker to move from a low-skill manual task—inspecting a dynamic or unsafe environment, carrying a heavy load, or performing a repeated task—to a high-skill conceptual task, like programming the robot or monitoring and troubleshooting the system.

These industrial robotic systems have typically required clear separation—usually in the form of a cage or fenced area—between the robot and the human workers. More recently, a new category of robot has emerged called Collaborative Robots or Cobots. These robots prioritize safety and human-robot interaction, allowing humans to work alongside the robot system. Paired with the integration of mobile robotic platforms, autonomous ground vehicles like forklifts, and other autonomous systems, the distinction between the robot's environment and the human workers has begun to blur. Cobots and other systems are enabling human workers and robots to leverage each of their advantages to complete tasks where the strengths of robots such as high precision, repeatability, and strength are combined with human intelligence and flexibility (Maoudj et al. 2018)

Given the changing environment in the workplace with industrial robots and the evolving technology needed to produce personal and service robots, a highly skilled workforce is needed and training for these workers must be further developed (ARM 2021). There are key industrial manufacturing sectors that have been identified through research and roadmapping by the Advanced Robotics for Manufacturing (ARM) institute to improve the robotics manufacturing supply chain and workforce including aerospace, automotive, electronics, and textiles (ARM 2021). Advances in versatile robotic systems, collaborative robotics (cobots), and methods to re-purpose and quickly deploy robotic systems have been identified as the highest priority technology development efforts for the industry (ARM 2021).

ARM has already been proactive in understanding the skills needed by the robotics industry. Specifically, they have developed Industry 4.0 Competency Building Blocks that outline technical skills for three key positions including Robotics Technician, Robotics Specialist, and Robotics Integrator. The framework also outlines essential soft skills such as critical thinking, teaming, and leadership. Using the Robotics Technician building blocks,

we selected BLS skills that were equivalent (see Table 24) since this position represents the technician equivalent as the Fundamental Industry 4.0 position. This study builds on this prior work by quantifying skills gaps for the key building blocks.

Methods

Workforce needs and gaps have been identified for the robotics industry through interviews of firms within the robotics manufacturing supply chain. Four steps were used to develop and structure the interview. These were: 1) discern the firms that make up the industry of interest; 2) posit occupations most relevant to those firms and skills most relevant to those occupations; 3) develop and deploy a semi-structured interview to characterize the relative importance of those occupations and skills; and 4) analyze the results to identify workforce and skills gaps (see Figure 1). More details of the research method are provided in the appendix to this report.

Discern emerging advanced manufacturing industries

The global robotics industry is valued at \$23.67 billion growing to \$74 billion by 2026 (Mordor Intelligence 2021). The D&B Hoovers Proprietary SIC 8-digit Code (SIC8) classification system (Cramer 2017), an expansion of the original SIC system, was used to discern the firms that comprise the robotics industry. These firms were mapped to industrial classification codes used by the Bureau of Labor Statistics (these are modifications of three to four-digit NAICS codes) to characterize workforce levels and economic activity by sector within the US economy. The specific codes and sectors that were used to represent the robotics industry are listed in Table 14 and Table 15 in the Appendix. The detailed process used to classify firms is described in the Appendix section, Detailed Methods.

Posit Relevant Occupations and Skills

Identify Relevant Occupations

To leverage the extensive surveying knowledge embedded within the US Department of Labor O*NET database (U.S. Department of Labor 2020), we use the BLS equivalent NAICS codes to identify a relevant set of occupations for our industry of interest. Specifically,



Figure 1. Key steps in the research method applied in this study.

occupation codes were identified using a combination of the 2018 National Employment Matrix (NEM) (U.S. Bureau of Labor Statistics 2018) and the O*NET database.

Middle-skilled workers are often defined as those with an education level beyond a high school diploma and less than a Bachelor's degree (Fuller and Raman 2017). Occupations are always held by workers with a range of education. For this research, we define middle-skilled occupations to be those for which both greater than 30% of the workforce is middle-skilled and less than 50% of the workforce is either lower-skilled or upper-skilled.

Based on these definitions, we identified 17 relevant middle-skilled positions associated with the robotics industry. These positions were validated through interviews with several industry stakeholders before firm interviews were launched. The ARM Industry 4.0 Competency Building Blocks framework was also consulted to compare the selected positions to the three positions defined in the framework.

To facilitate interview-based data collection, these occupations were organized into seven representative groups, as shown in bold in Table 1. This set includes five types of engineering technicians – electrical / electronic, electro-mechanical, industrial, mechanical, and chemical/materials– as well as technical maintenance personnel (e.g., mechanics, electricians), computer-numerical-controlled machine operators, and machinists.

Table 1. Focal occupations that were evaluated in this study. Bold titles represent representative occupations that were served as proxy for the subsequent specific occupations.

Occupation	Standard Occupation Classification Code
Middle-skilled	
Electrical and electronics engineering technicians(representing)	
Electrical and electronics engineering technicians	17-3023
Electrical and electronics drafters	17-3012
Electro-mechanical technicians	17-3024
Industrial engineering technicians(representing)	
Industrial engineering technicians	17-3026
Aerospace engineering and operations technicians	17-3021
Mechanical engineering technicians(representing)	
Mechanical engineering technicians	17-3027
Mechanical drafters	17-3013
Chemical technicians	19-4031
Maintenance and Support Technicians (representing)	
Industrial machinery mechanics	49-9041
Maintenance workers, machinery	49-9043
HVAC mechanics and installers	49-9021
Mobile heavy equipment mechanics, except engines	49-3042

Electrical & electronics repairers, commercial & ind. equipment	49-2094
Computer-controlled machine tool operators(representing)	
Computer-controlled machine tool operators	51-4011
Computer numerically controlled machine tool programmers	51-4012
Other Technical Production Worker (representing)	
Machinists	51-4041
Tool and die makers	51-4111
Installation and deployment technicians	See note in results section

Identify Relevant Skills

For each identified occupation, an associated set of competencies (skills) and tools was developed from two sources of job characterization information: the U.S. Department of Labor O*Net database (U.S. Department of Labor 2020) and a real-time labor market intelligence analytics database, Burning Glass Labor Insight™ ((Burning Glass Technologies 2021). The O*Net database uses a hierarchical taxonomic approach to organize tasks and skills. (Peterson et al. 2001). The database was originally developed through survey methods to create a relational database of occupation attributes for the U.S. economy (Peterson et al. 2001)and helps create a common language for job descriptors. For each occupation, the database includes tasks in the job, tools employed in the job, and technologies employed on the job.

Using all of this information, the research team selected six to ten technical skills for each occupation based on the O*NET task descriptions to characterize their importance and any existing skills gap for these skills within the robotics industry. The specific skills explored are listed in the results plots and tables in the results section of the report.

Emerging Technical Skills

While the O*NET database provides valuable insight into the current technical skills needed for these occupations, the research team also wanted to get a sense of what important skills are emerging within the robotics industry.

To accomplish this, we made use of two methods to identify potentially relevant emerging skills. The first method relied on discussions of the changing nature of work within the academic literature. Specifically, based on information within the MIT Production in the Innovation Economy (PIE) survey (Weaver and Osterman 2017), the essential skills framework used by the Canadian government (Government of Canada 2015), and the Future of Work report (Autor, Mindell, and Reynolds 2020). Based on the authors' synthesis of these reports, we identified the following skills as potentially relevant and emerging for technical middle-skilled workers in manufacturing:

- Programming and troubleshooting automated process equipment (CNC, programmable production equipment, etc.)

- Conducting and assessing the results of statistical process control analyses or design of experiments
- Optimizing production flow based on the use of qualitative observations and quantitative analytics
- Using lean manufacturing principles (value stream mapping, minimize waste)
- Decreasing inventory and stockouts by understanding your own operations and your suppliers
- Working with digital collaboration tools (Computerized maintenance management software, connected worker platforms, workflow management, etc.)

The second method was to make use of a real-time labor market intelligence analytics database to identify emerging skills for each occupation. Burning Glass Labor Insight™ (BGLI) collects job posting data from job boards, firm websites, and job ad websites that represent more than 40,000 online resources and 3.4 million jobs (Burning Glass Technologies 2021). Duplicate postings are removed and natural language processing methods extract the in-demand occupations, skills, and credentials. Two approaches were used to identify relevant skills list from the BGLI database. It is important to note that while we did not specifically include tools and technologies in our interviews due to limited time; however, knowledge of in-demand tools and technologies can help inform trends in the robotics industry.

In the first approach, referred to as a keyword-based query, we attempted to identify relevant skills by querying middle-skilled posting associated with manufacturing and with the keywords “robotic(s)” or “automation”. Specifically, we applied the filters shown in Table 2 which yielded 130,456 job postings. Finally, we added a filter where the job title must include “technician” resulting in 37,557 postings. Comparison between these two queries (with “technician” and without), helped to highlight technician-specific skills and isolate skills that are typical for all types of middle skilled positions within the industry (e.g. Microsoft Office Suite).

Table 2. Filter criteria applied for relevant education levels and keywords in the Labor Insight™ database.

Criteria	Filter Applied
Time Period	07/01/2016-06/31/2021
Education	High school or vocational training or Associate's degree
Industry	Manufacturing
Keywords	Robotic, robotics, automation
Location	Nationwide
Title includes	Technician

In a second approach, referred to as an employer-based query, we searched for relevant and current skills by querying postings specifically associated with the three middle-skilled technician positions identified within BGLI – robotics technician, industrial/mechanical engineering technician, or general engineering technician – and with firms specifically known to be in the robotics industry. The filtering on employer and types of occupations as shown in Table 3, resulting in 5,326 job postings. To once again narrow the search and reduce noise in the dataset, the “technician” filter was added, reducing the number of postings to 2,926.

Table 3. Filter criteria applied for relevant employers and occupations in the Labor Insight™ database.

Criteria	Filter Applied
Time Period	07/01/2016-06/31/2021
Occupation(s)	Robotics technician or general engineering technician or industrial/mechanical engineering technician
Employer	180 robotics firms
Location	Nationwide
Title includes	Technician

The top 200 skills were identified from both approaches and compared with the O*NET tasks, detailed work activities, tools (and examples), and technologies (and examples) associated with the four technician positions found in both databases: electrical engineering technicians, mechanical engineering technicians, industrial engineering technician, and electro-mechanical and mechatronic technicians.

To identify skills not represented in the O*NET database, we performed a two-stage assessment. First, an NLP tool, UDPipe in R (Wijffels 2021), was used to lemmatize⁴ the text of both the BGLI skills and the O*NET data and, then, to identify matches between the two. Matches and partial matches of at least 25% commonality were flagged for human evaluation. Based on this, skills or tools that were present in BGLI but not in O*NET were flagged to ensure all emerging skills, tools, and technologies are identified to inform curriculum development and training.

The O*NET database is a source of comprehensive job classification information with detail and context that is needed for in person interviews. The BGLI data is uniquely able to identify emergent skills and technologies in the field, but the information can require effort to contextualize given their brevity and occasional specificity. Overall, O*NET and

⁴Lemmatization is a linguistics process of combining the inflected parts of a word to analyze them as a single item. It is a common natural language processing technique.

Burning Glass Labor Insight™ complement one another in the skills gap analysis for the robotics industry.

Delays in accessing the BGLI database and the pressing need to deliver results in a timely manner, resulted in BGLI results not being available *before* interviews began. As such, for this report, we were unable to explicitly include emerging skills flagged by the BGLI analysis within industry interviews. While there were very few such skills that were absent from the survey questions, it is still important to identify them. As such, we call these out in the results section in Figure 13 and Appendix Figure 19-Figure 21 and Table 20-Table 23 and recommend that all programs monitor the importance of these skills to their local industry.

Human Skills: What about “Soft” skills?

The focus of this study was to assess the training gaps associated with specific applied skills for technical workers. This focus in no way implies that the research team believes that such technical skills are more important than other non-technical skills (also known as “soft” or human skills). Research was focused on technical skills for two reasons. First, our primary goal was to develop insights to shape training programs aimed to support the robotics industry. Such programs themselves focus on technical skills and, therefore, require feedback on the same. Secondly, the interview applied in this research was of a scale that taxed most respondents. As such, tradeoffs had to be made to limit its scope and content. As a result, this study explores only a limited set of human skills including a novel analysis of critical thinking.

Although they were not the focus of this study, it is important for training programs to recognize that human skills complement technical skills, enhance employability, and improve productivity (Schulz 2008; Rao 2014). Although both industry and academia are reaching consensus that employees need human skills in addition to the technical skills taught in most STEM training programs (Kumar and Hsiao 2007), there is no consensus on which human skills are most important or even how to frame and organize human skills.

A recent study by researchers at MIT's Jameel World Education Lab attempts to bridge that gap by synthesizing more than 40 skills frameworks into the Human Skills Matrix (HSM). Their analysis found that communication and self-management skills were the most commonly identified important human skills. These were followed by creativity, problem solving, critical thinking, and teamwork. The HSM synthesizes this information into 24 non-technical skills that employees need to thrive (Stump, Westerman, and Hall 2020). These skills are grouped into four categories including Thinking, Interacting, Managing ourselves, and Leading. This framework was used to guide the selection of human skills studied here.

Specifically, we asked operations managers about the importance of these six human skills (as well as a detailed question about critical thinking) for middle-skilled manufacturing occupations:

- Effectively managing people and projects (Leading)
- Managing unfamiliar problems and situations (Thinking)
- Independently organizing time or prioritizing tasks (Managing ourselves)
- Communicating and collaborating with engineering and management staff (Interacting)
- Taking initiative to learn new skills or technologies (Managing ourselves)
- Knowing the science and engineering underlying the product (Thinking)

Critical thinking is widely cited as a skill that leads to success. Nevertheless, there are no established methods to characterize it. Here we define critical thinking as “the ability to analyze evidence and facts to form a judgment” (Gambrill 2005). To better characterize the role of critical thinking for technical middle-skilled occupations, we decompose the judgment process into the following sub-tasks:

1. Perceiving the issue – What should I measure or observe to know that a problem exists?
2. Hypothesizing about problem cause – What might be causing the problem?
3. Developing a framework for hypothesis testing – How can I confirm my hypothesis?
4. Inferring whether tests confirm the hypothesis - Does the test suggest that my hypothesis was right?
5. Communicating the outcome – How (and to whom) do I report on what has happened?

Respondents were asked to identify what aspect of critical thinking is important of technicians working at their facility.

Identifying Important, Common Skills

While it is valuable to understand the skills trends within individual occupations, in many cases, training programs or courses will need to be more broadly applicable, serving the needs of multiple types of learners. Combemale et al. (2021) also recommend that formal training must become more general for technician-level positions to be valuable in various types of advanced manufacturing industries. To that end, the research team has attempted to identify those skills that are both important and shared (common) among multiple occupations.

This was accomplished by making use of the hierarchical nature of the O*NET dataset from which occupation-specific skills were identified. Weighted average importance levels for generalized tasks/skills (GTS) and intermediate tasks/skills (ITS) were computed based on survey responses for occupation-specific tasks and skills. Details of the relationships among specific skills and higher levels of aggregation and the method of computing an importance score are described in the Appendix.

Semi-Structured Interview

Interview design

The interview is structured into four main sections:

- 1) firm characterization,
- 2) hiring and training challenges
- 3) workforce scaling, and
- 4) emerging and human skill needs including critical thinking.

In the first section of the interview, respondents were asked to identify the primary role that their firm plays in the robotics supply chain. Additionally, respondents were asked to estimate the firm's annual revenues and overall employment levels.

In the second section, respondents were asked to identify which of the focal occupations were relevant for their firm. Then for each relevant occupation they were asked whether

- Demand for that position would (Hold, Grow Somewhat, or Grow Significantly)?
- Filling an open position was (Easy, Average, or Hard)?
- In house training for new hires tends to be (Basic, Moderate, or Extensive training)?

Next, respondents were randomly assigned three relevant occupations. For each of these, they were asked to characterize the expected skill level for each position for their current technicians, the skill level of new hires for these positions, and rank the importance of the skills in 5 years compared to today. The categories for skill level included the following:

- Not applicable
- Aware of
- Familiar with
- Competent at
- Proficient with
- Mastery of

The expected importance ranks from much less important than now to much more important than now.

For each of these positions, respondents were asked to evaluate the importance of emerging skills when evaluating a new hire in five years. The importance categories included the following:

- Extremely important
- Very important
- Moderately important
- Slightly important
- Not at all important

Finally, the closing questions of the interview included in-depth questions about critical thinking and troubleshooting for technicians relevant to the respondent's firm. The respondents were asked to identify which of the judgments in the critical thinking process were most common for each technician ranging from:

- Issue perception
- Cause hypothesizing
- Hypothesis testing
- Test result inference
- Reporting and recommending

It was assumed that if a respondent chose "reporting and recommending" then they felt that the technician was capable of performing all of the previous steps as well.

To understand the importance of troubleshooting for hiring, respondents were asked to explain the relevance of this ability at their firm and how they test and train troubleshooting abilities.

Semi-Structured Interview Process

The interview responses were captured in the Qualtrics online platform (Qualtrics XM 2021) and interviews were conducted with robotics firms located in the New England area. Thirty-one responses where the respondent completed the entirety of the interview template were received and incorporated into the following results.

Results

Interview results from thirty-one firms across the robotics supply chain underscore the increasing demand for middle -skilled technical workers and demonstrate the growing skills gaps for new and incumbent workers. The first section details responses about the overall demand for middle-skilled workers with projections for future demand for these workers. The results also highlight training and hiring challenges firms face for each position studied. The remaining sections demonstrate the importance of specific technical skills by position and show the skills gap for each skill. High and moderate priority skills are identified based on firms' characterization of the gap and future importance. Recommendations for emphasis on high and moderate priority skills are included to help focus future curriculum development and training programs.

Demand for occupations

Question

We expect demand for this type of position in our firm will....

In the future, firms indicated that the demand for all positions evaluated in the study is strong and will continue to grow (Figure 2. The technical worker occupations studied were classified according to future demand growth in the robotics industry. Number of respondents, n =31.). The position that is expected to have the highest demand in the future is electro-mechanical or mechatronics engineering technicians due to the robotics field requiring knowledge of both electrical and mechanical engineering principles. Telling of its importance to this industry, this position is often referred to simply as "robotics technician". Electrical and mechanical engineering technicians are also expected to be in great demand due to trends within the industry. For example, in the next few years, many firms are likely to design their own platforms internally, especially at robotic arm companies, and therefore will need technicians in house to build. Installation and deployment technicians are also expected to have significant growth. Deployment technicians were emphasized by several firms where firms are seeking technicians that have both a customer facing personality as well as the ability to perform technical work.

CNC Operators and Maintenance Technicians are expected to have moderate demand growth and are positions that were common among many of the firms. The positions with the largest amount of 'not applicable' responses were chemical/materials technicians and industrial engineering technicians. This suggests that these types of workers are not universal for robotics firms and while the number of these positions will expand with the industry, it will do so at a rate less than other positions. Overall, these results suggest that curricula that emphasizes electrical and mechanical engineering skills will be invaluable to robotics firms and curricula that addresses the skills necessary for deployment technicians will aid in growing the robotics industry in the U.S.

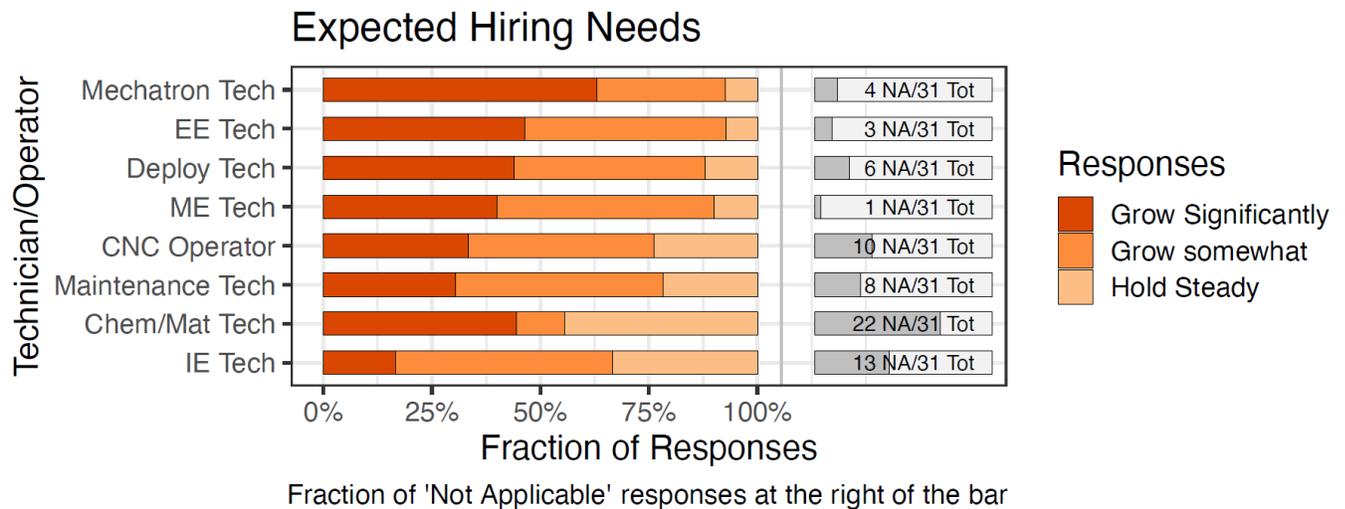


Figure 2. The technical worker occupations studied were classified according to future demand growth in the robotics industry. Number of respondents, n =31.

The demand for each position can be summarized as follows:

Strong Growth	Moderate Growth	Hold
<ul style="list-style-type: none"> • Mechatronics Technician • Electrical Engineering Technician • Installation and Deployment Technician 	<ul style="list-style-type: none"> • Mechanical Engineering Technician • CNC Tool Operator • Maintenance and Support Technician 	<ul style="list-style-type: none"> • Chemical/Material Technician • Industrial Engineering Technician

Workforce Demand Projections

To better understand the growth trends in the robotics industry, an econometric analysis was performed to project the expected number of positions and openings within the industry. This projection was based on three sources of data: forecasts for the overall economic activity within the U.S. robotics industry, estimates of worker intensity per dollar of economic activity within the represented sectors, and interview responses about specific staffing levels and anticipated growth in demand for specific occupations.

Estimates of economic activity within the U.S. robotics industry were assembled from three sources of market intelligence including industry statistics from the Robotic Industries Association (Association for Advancing Automation 2021), International Federation of Robotics' presentation on annual robot installations (International Federation of Robotics 2020), and the Bureau of Labor Statistic's *Projections Overview and Highlights, 2019-2029*

(Dubina et al. 2020). From these sources of information, we estimate the robotics for manufacturing industry within the United States currently generates approximately \$2B of revenue and is projected to grow at a rate of approximately 15% per year. (To be more conservative, we use this rate of growth only for the first five years of our analysis. For the latter five years, we assume a 10% rate of growth.) Estimates of workforce intensity (i.e. workers per dollar of revenue) are based on analysis of BLS data for the hybrid industry that is used here to represent the robotics industry.

Because interview results highlighted the growing demand for robotic deployment technicians, an analysis was performed to estimate the existing and future openings for deployment technicians as the robotics industry grows. Robotic deployment technician is not a position that currently exists in the BLS database but is one that robotics firms emphasized as extremely important for their operations. As such, we identified relevant industries likely to have robotic technology (e.g. testing laboratories, commercial and industrial machinery and equipment, and others) and assumed 25% of the electro-mechanical technicians in these industries are robotic deployment technicians.

Note: in the balance of this section, in the interest of simplicity, we refer to technical middle-skilled positions. As was detailed earlier in this document, our analysis includes only specific occupation types. For middle-skilled occupations, the primary omission is information technology positions.

As shown in Figure 3, we estimate that currently there are ~4,000 technical middle-skilled positions in the U.S. robotics industry with that figure growing to just under 7,500 positions by the end of the decade (Figure 3a). The expected growth coupled with expected departures from the existing workforce (i.e., retirements and separations into other occupations) would lead to nearly 10,000 middle-skilled skilled technical openings over the decade. The analysis projects ~600 openings per year for robotic deployment technicians alone.

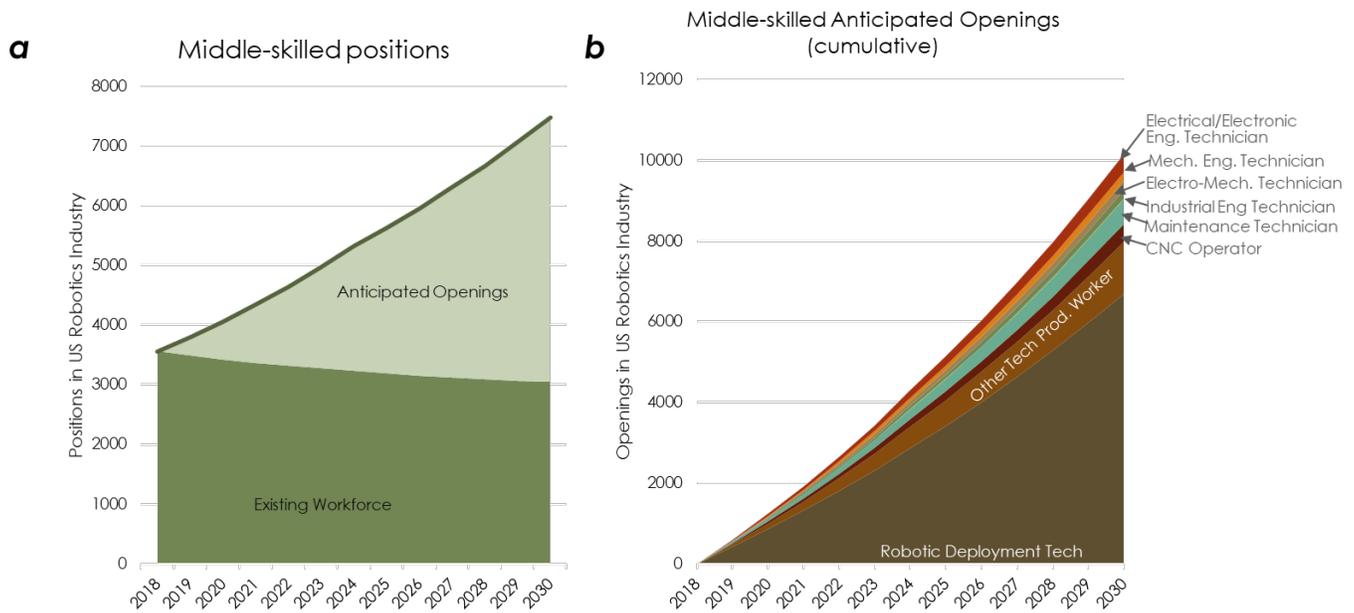


Figure 3. (a) Shows an overview of trends for middle-skilled workers in the robotics industry (b) Provides details by position. Results are based on expected demand growth, industry growth, and retirement rate.

These estimates translate into a need of about 870 new middle-skilled workers per year. If a typical community college program graduates 15 middle-skilled learners with these skills per year, the country will need more than 58 programs focused on the needs of the robotics industry to meet the expected industry demand for middle-skilled workers. Another clear recommendation that emerges from these numbers is the development of programs focused on deployment technicians since these workers are needed to deploy robotics across all the industries that incorporate robotics systems into their manufacturing processes.

Mapping these numbers to a Massachusetts context, we estimate around 275 positions today growing to 470 positions in 2030. This translates to about 54 middle-skilled openings per year, resulting in about 4 programs needed for training middle-skilled workers in the state.

Hiring Challenges

Question

Filling this type of position is

Respondents were also asked about how difficult each occupation is to fill. At this point in time, many respondents explained it is more difficult than usual to hire technicians due to pandemic-related challenges. However, even prior to the pandemic, many respondents indicated that hiring technicians such as electro-mechanical or mechatronics engineering technicians can be challenging (Figure 4). This is because technicians that have both electrical and mechanical knowledge and experience are

rare. Interestingly, none of the positions were easy to hire and all positions except other technical production worker, industrial engineering technician, and mechanical engineering technician had >50% of respondents indicate that the positions were difficult

“What engineers were doing three years ago, technicians are now expected to do.”
New England Advanced Robotics for Manufacturing Company Representative, June 2021

to fill. These results suggest a low supply of technical workers as well as a challenge of attracting and retaining workers in this industry.

When asked about how firms typically find candidates, they shared that they hire through temporary agencies or staffing companies or through networking at schools nearby. However, there is a high turnover rate especially at the technician level. For small companies especially, firms noted that they often lose technicians to larger companies and with a lot of existing technicians retiring, they don't have the internal capability to transfer knowledge.

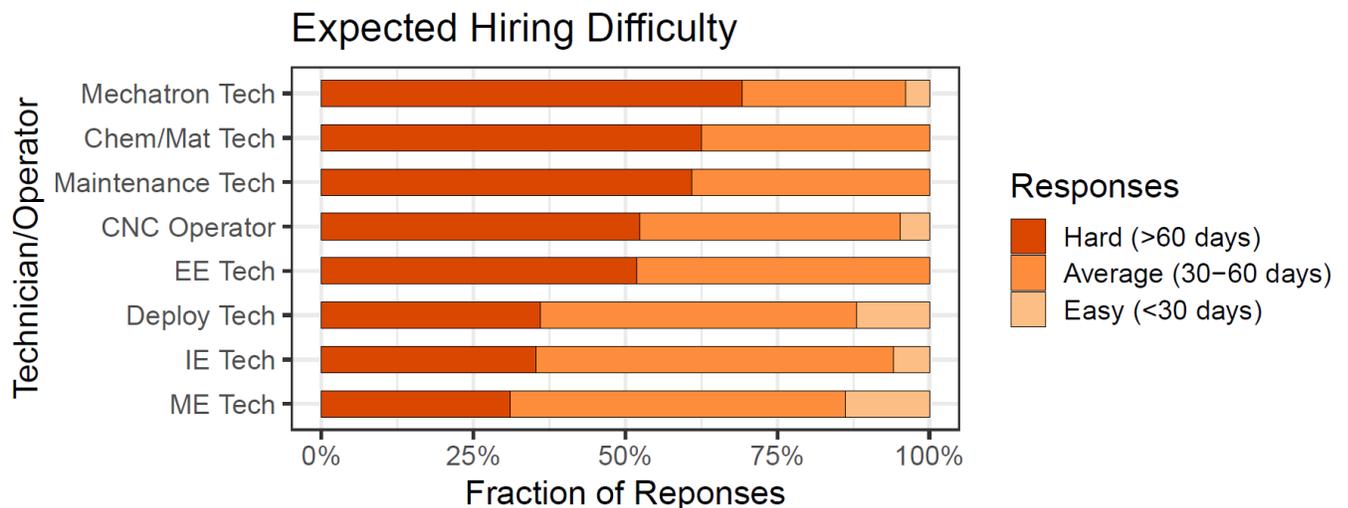


Figure 4 The difficulty of hiring middle-skilled positions was assessed for the robotics industry (n=31). Most positions were found to be difficult to fill.

The hiring difficulty for each position can be summarized as follows:

Considerable hiring effort	Moderate	Nominal
<ul style="list-style-type: none"> • Mechatronics Technician • Chemical/Material Technician • Maintenance and Support Technician • CNC Tool Operator • Electrical Engineering Technician 	<ul style="list-style-type: none"> • Installation and Deployment Technician • Industrial Engineering Technician • Mechanical Engineering Technician 	

In comparing the demand and hiring results, mechatronics technicians are the most in demand and most difficult positions to fill. While chemical/material technicians are difficult to hire, their demand growth is expected to hold steady. It is worth noting that mechanical engineering technicians are relatively easy to hire compared to the other positions and are in high demand at firms. This suggests that an emphasis on training and attracting electro-mechanical and mechatronics engineering technicians and electrical engineering technicians would be especially valuable for the robotics manufacturing industry.

Training Effort Required

Question
New hires typically require training that is ...

The amount of on-the-job training for each occupation was also evaluated by respondents as extensive, some, or basic orientation only. Many respondents noted that extensive training is required for most positions and can take up to six months in order for workers to be productive. They also noted that since intelligent automation and robotics is rapidly evolving, the jobs are also changing. There is demand for improved training of new hires as well as upskilling for existing workers. Specifically, respondents suggested additional or improved training in

- hydraulics,
- reading blueprints,
- programming and debugging,
- technical writing, and
- lean manufacturing

would help reduce the amount of training hours required by the firm. An emphasis in technical communication is also of interest to many firms since it is needed at every step of the production process.

The interview results showed that chemical/material technicians, maintenance and support technicians, and installation and deployment technicians require the most on-the-job training. Chemical/material technicians are not common at all robotics firms, but those that require this position feel that there is company-specific knowledge that must be taught regardless of the training level coming in. Maintenance and support technicians and installation and deployment technicians also required extensive training due to the equipment and programming languages unique to each firm. The engineering technician positions mostly require some training and the CNC tool operator requires the least amount of on-the-job training for the occupations studied. Additional exposure to diverse equipment and programming languages could help increase the supply of qualified workers. Many respondents suggested improve relationships among equipment suppliers and community colleges to enable a better understanding of the equipment in the industry.

To address these training challenges, several firms recommended apprenticeship programs as well as assistance in increasing the awareness among middle-skilled workers of how training can fit into broader career goals.

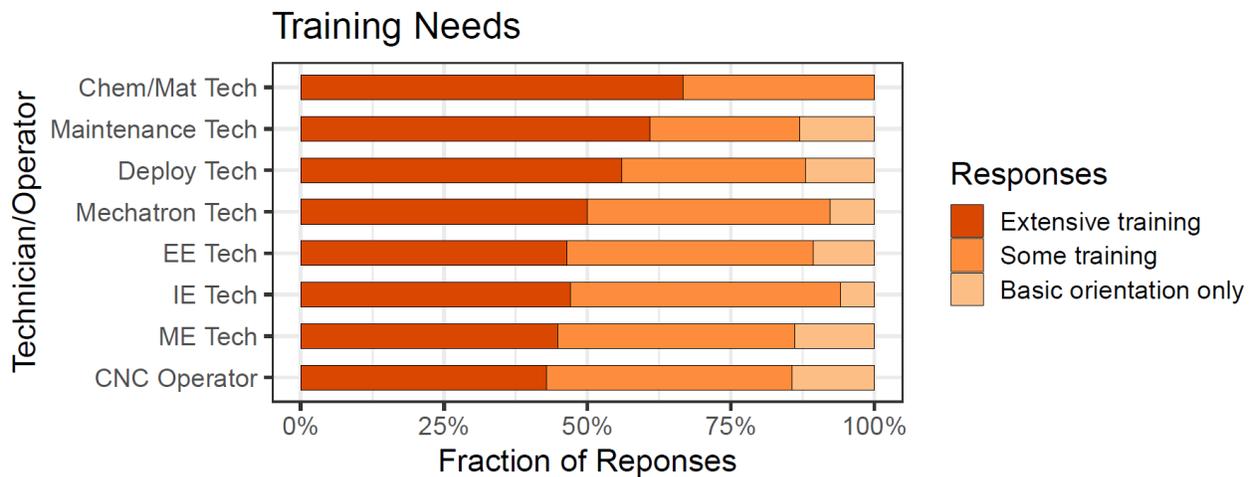


Figure 5 The training required for each position was assessed as extensive, some training, or basic orientation only (n=31). Most of the middle-skilled positions required extensive training (>50% of the responses) and the remaining positions required at least some training.

In comparing the training effort results to the hiring challenge results, we observe that many of the middle-skilled positions are difficult to hire and also require additional specialized training for new hires.

The training challenges for each position can be summarized as follows:

Extensive training	Some training	Basic orientation only
<ul style="list-style-type: none"> • Chemical/materials Technician • Maintenance and Support Technician • Installation and Deployment Technician • Mechatronics Technician 	<ul style="list-style-type: none"> • Electrical Engineering Technician • Industrial Engineering Technician • Mechanical Engineering Technician • CNC Tool Operator 	

Industry Recognized Certification Program

Question

How do you feel about the following statement: "Industry-Recognized Certifications and Credentials would be useful for the advanced robotics manufacturing industry."

During the interviews, the firms were asked to rank how they felt about job-specific industry-recognized certification and credentialing programs to assist with hiring from strongly disagree to strongly agree (Figure 6). The goal of these programs would be to aid in identifying qualified candidates and to provide opportunities for more workers. Most respondents (77%) either strongly agreed or agreed with the statement that industry specific credentials would be useful for the robotics industry. Only one respondent disagreed and the remaining respondents indicated that they were neutral regarding certification programs.

Many respondents felt that credentialing could contribute to qualifications, signals interest, yet is certainly not a requirement. A certificate/credential implies an ability to learn and work to a certain standard. However, many respondents noted that robotics is a broad field and therefore certain applications and equipment are not universal. Specifically, respondents

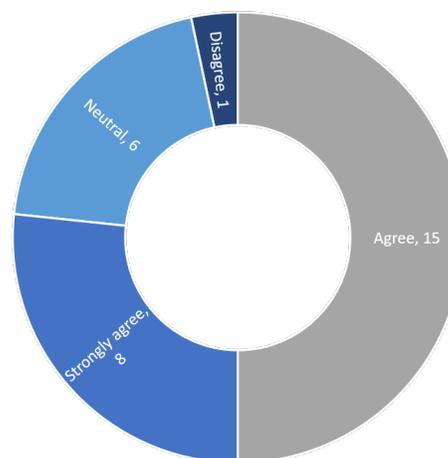


Figure 6 Reactions regarding certification and credentialing programs to improve hiring in the advanced robotics for manufacturing industry.

indicated an interest in focused areas such as safety certifications, programming, and/or CAD courses. Those that disagreed with this type of program explained that if the program were free/open courseware, it would be much more appealing. Otherwise, it would be a barrier to entry into the field. In addition to credentials/certificates for new hires, many respondents also indicated that upskilling for the existing workforce through re-certification would also be of interest.

Skills required for In-Demand Positions

Interview results demonstrate the growing demand for middle-skilled workers in the robotics industry, significant hiring and retention challenges, and training gaps for robotics manufacturing workers. The training gaps for each occupation were explored in detail for 8-10 specific skills where respondents were asked to rank the skill level for existing workers, new hires, and the importance of the skill in five years compared to today. The research team identified skills that were classified as high priority or moderate priority. High priority skills are those that have a large gap between existing workers and new hires and were also ranked as important. Moderate priority skills are those with either a large gap or were ranked as much more important or skills that fell in the mean range of the data for both categories. For those skills that were not ranked as high or moderate priority, the research team recommends these skills be re-evaluated for inclusion in the curricula for that occupation.

There were a sufficient number of responses ($n \geq 5$) to characterize five positions including mechatronics technicians, mechanical engineering technician, electrical engineering technician, industrial engineering technician, and CNC tool operator. Since there are significant training gaps for these workers, we highlight opportunities to improve training programs for the future.

Table 4 Occupation descriptions for the six positions with a sufficient number of responses.

Occupation Title	Description
Mechatronics Technicians (SOC Code 17-3024.00)	Operate, test, maintain, or adjust unmanned, automated, servomechanical, or electromechanical equipment. May assist engineers in testing and designing robotics equipment.

Occupation Title	Description
Mechanical Engineering Technicians (SOC Code 17-3027.00)	Apply theory and principles of mechanical engineering to modify, develop, test, or calibrate machinery and equipment
Electrical Engineering Technicians (SOC Code 17-2023.00)	Apply electrical and electronic theory and related knowledge, usually under the direction of engineering staff, to design, build, repair, adjust, and modify electrical components, circuitry, controls, and machinery for subsequent evaluation and use by engineering staff in making engineering design decisions.
Industrial Engineering Technicians (SOC Code 17-3026.00)	Apply engineering theory and principles to problems of industrial layout or manufacturing production. May perform time and motion studies on worker operations in a variety of industries to establish standard production rates or improve efficiency
Chemical/Materials Technician (SOC Code 19-4031)	Conduct chemical and physical laboratory tests to assist scientists in making qualitative and quantitative analyses of solids, liquids, and gaseous materials for research and development of new products or processes, quality control, maintenance of environmental standards, and other work involving experimental, theoretical, or practical application of chemistry and related sciences.
CNC Tool Operators (SOC Code 9161.00)	Operate computer-controlled tools, machines, or robots to machine or process parts, tools, or other work pieces made of metal, plastic, wood, stone, or other materials. May also set up and maintain equipment.

Mechatronics Engineering Technician

Survey responses for mechatronics technicians are shown in Figure 7. Recommendations for training based on these results are summarized in Table 5. The skills on the left are drawn from O*NET descriptions of work activities for specific job classifications. The green line represents the competency stated for new hires into the position. The red line is the competency stated for current employees in the position. The proportional change in importance in five years is represented by the blue circles. In this study, we interpret that

change in importance to indicate that future competency levels for those tasks will need to shift accordingly.

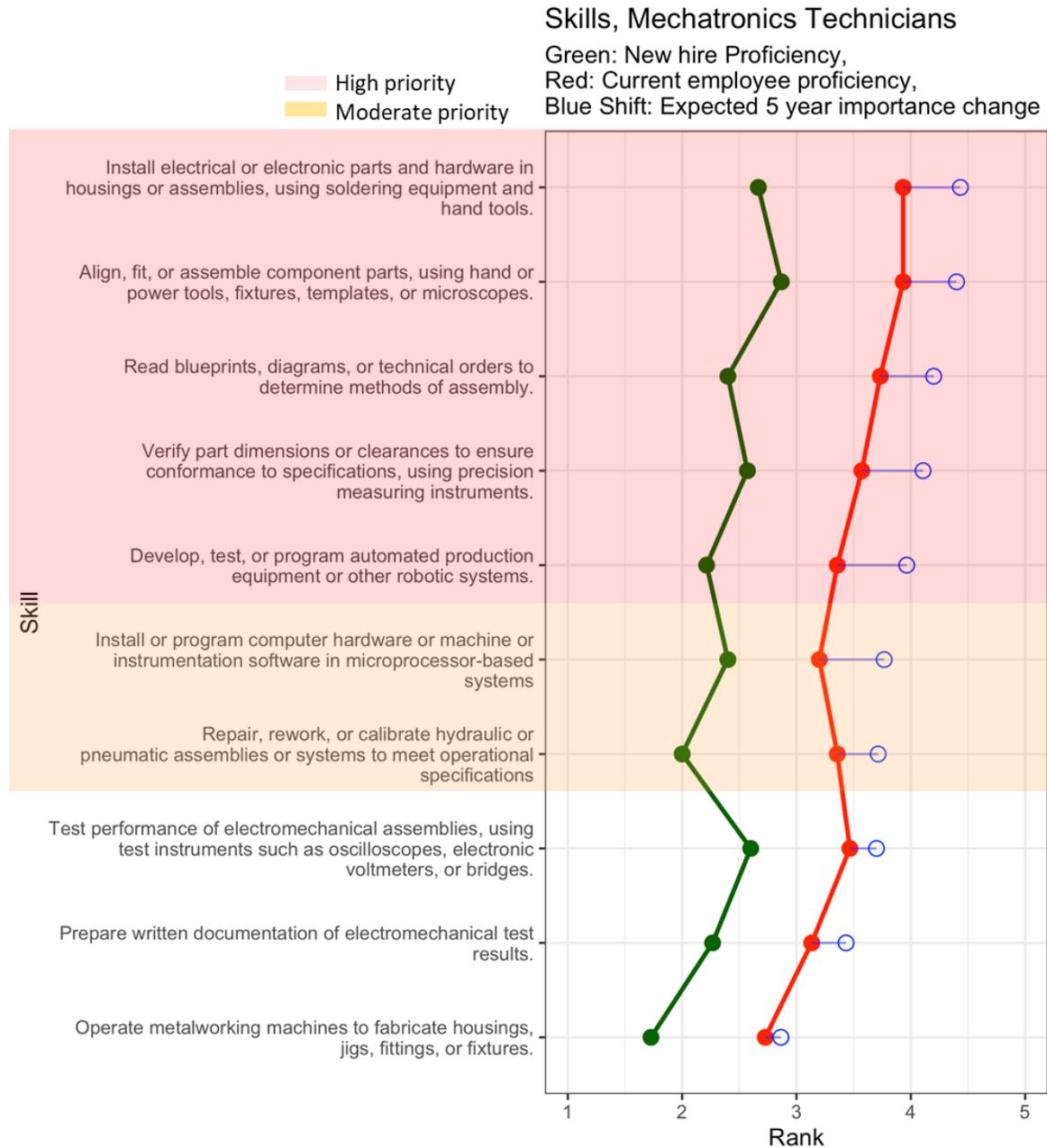


Figure 7. The gaps and expected future importance of skills for mechatronics technicians are shown with high priority skills highlighted in red and moderate priority skills highlighted in orange.

Table 5. Recommended changes in the training of mechatronics technicians in the robotics industry. The orange skills are those that are ranked as moderate priority and therefore have a skill gap and are also important in the future.

Recommendation	Skill	Full Skill Description
Emphasize training on...	Fabricate components and systems	Install electrical or electronic parts and hardware in housings or assemblies, using soldering equipment and hand tools.
		Align, fit, or assemble component parts, using hand or power tools, fixtures, templates, or microscopes.
	Understand, evaluate, and maintain quality	Read blueprints, diagrams, or technical orders to determine methods of assembly.
		Verify part dimensions or clearances to ensure conformance to specifications, using precision measuring instruments.
Improve training on...	Develop, test, and program hardware systems	Develop, test, or program automated production equipment or other robotic systems
		Install or program computer hardware or machine or instrumentation software in microprocessor-based systems
	Hydraulic or pneumatic assembly repair	Repair, rework, or calibrate hydraulic or pneumatic assemblies or systems to meet operational specifications
Maintain training/evaluate training on...	Use test instruments	Test performance of electromechanical assemblies, using test instruments such as oscilloscopes, electronic voltmeters, or bridges.
	Prepare reports	Prepare written documentation of electromechanical test results.
	Operate metalworking machines	Operate metalworking machines to fabricate housings, jigs, fittings, or fixtures

Mechanical Engineering Technician

Survey responses for mechanical engineering technicians are shown in Figure 8. Recommendations for training of mechanical engineering technicians based on these results are summarized in Table 6.

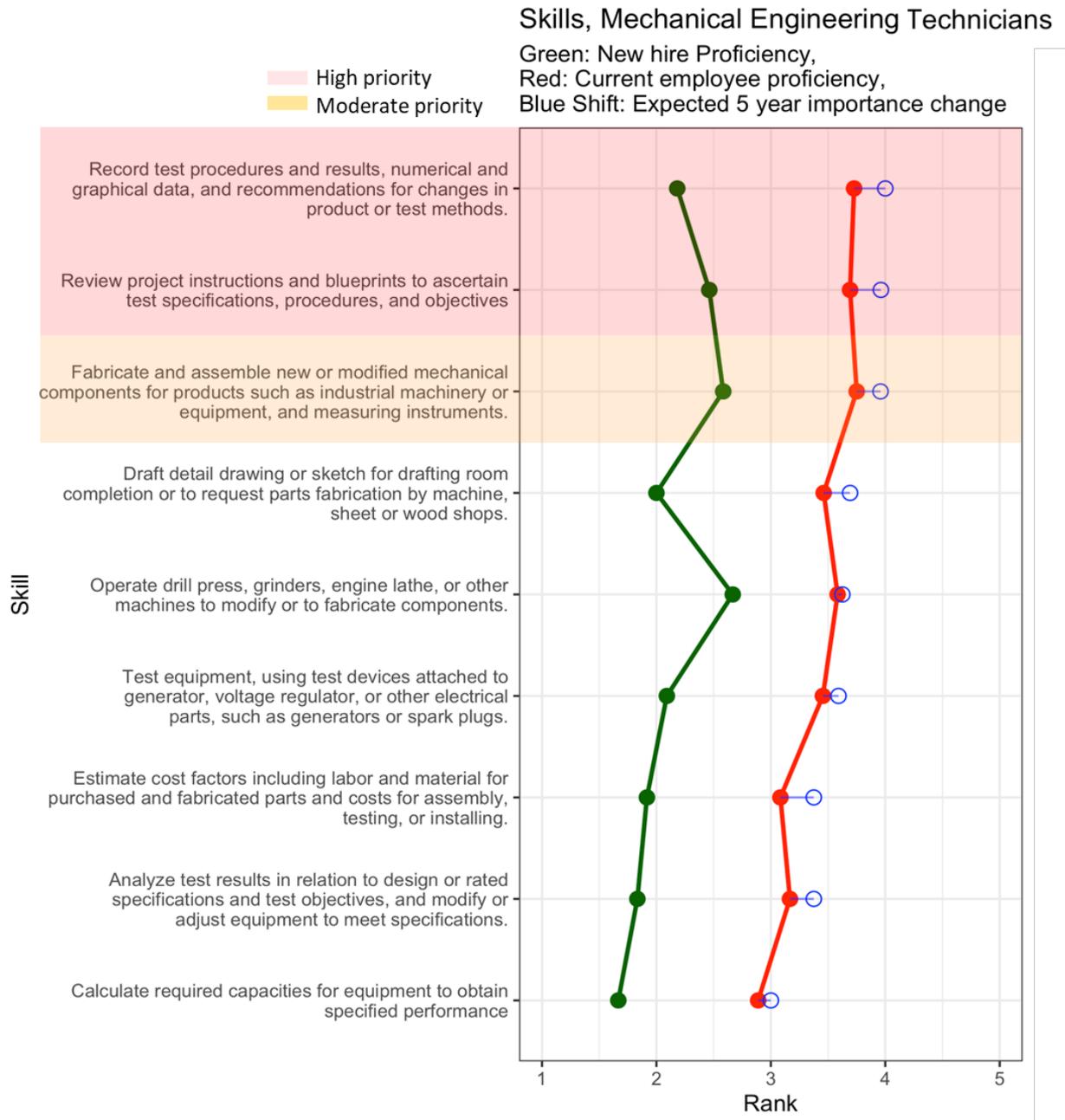


Figure 8. The gaps and expected future importance of skills for mechanical engineering technicians are shown with high priority skills highlighted in red and moderate priority skills highlighted in orange.

Table 6. Recommended changes in the training of mechanical engineering technicians in the robotics industry. The orange skills are those that are ranked as moderate priority and therefore have a skill gap and are also important in the future.

Recommendation	Skill	Full Skill Description
Emphasize training on...	Recommend changes in product or process design	Record test procedures and results, numerical and graphical data, and recommendations for changes in product or test methods.
	Understand, evaluate, and maintain quality	Review project instructions and blueprints to ascertain test specifications, procedures, and objectives
Improve training on...	Fabrication methods	Fabricate and assemble new or modified mechanical components for products such as industrial machinery or equipment, and measuring instruments.
Maintain training/evaluate training on...	Drafting for fabrication	Draft detail drawing or sketch for drafting room completion or to request parts fabrication by machine, sheet or wood shops.
	Estimate system capabilities and costs	Estimate cost factors including labor and material for purchased and fabricated parts and costs for assembly, testing, or installing.
		Calculate required capacities for equipment to obtain specified performance
	Understand, evaluate, and maintain quality	Analyze test results in relation to design or rated specifications and test objectives, and modify or adjust equipment to meet specifications.
		Test equipment, using test devices attached to generator, voltage regulator, or other electrical parts, such as generators or spark plugs.
	Operate specific equipment	Operate drill press, grinders, engine lathe, or other machines to modify parts tested or to fabricate experimental parts for testing.

Electrical Engineering Technician

Survey responses for electrical engineering technicians are shown in Figure 9. Recommendations for training of electrical engineering technicians based on these results are summarized in Table 7.

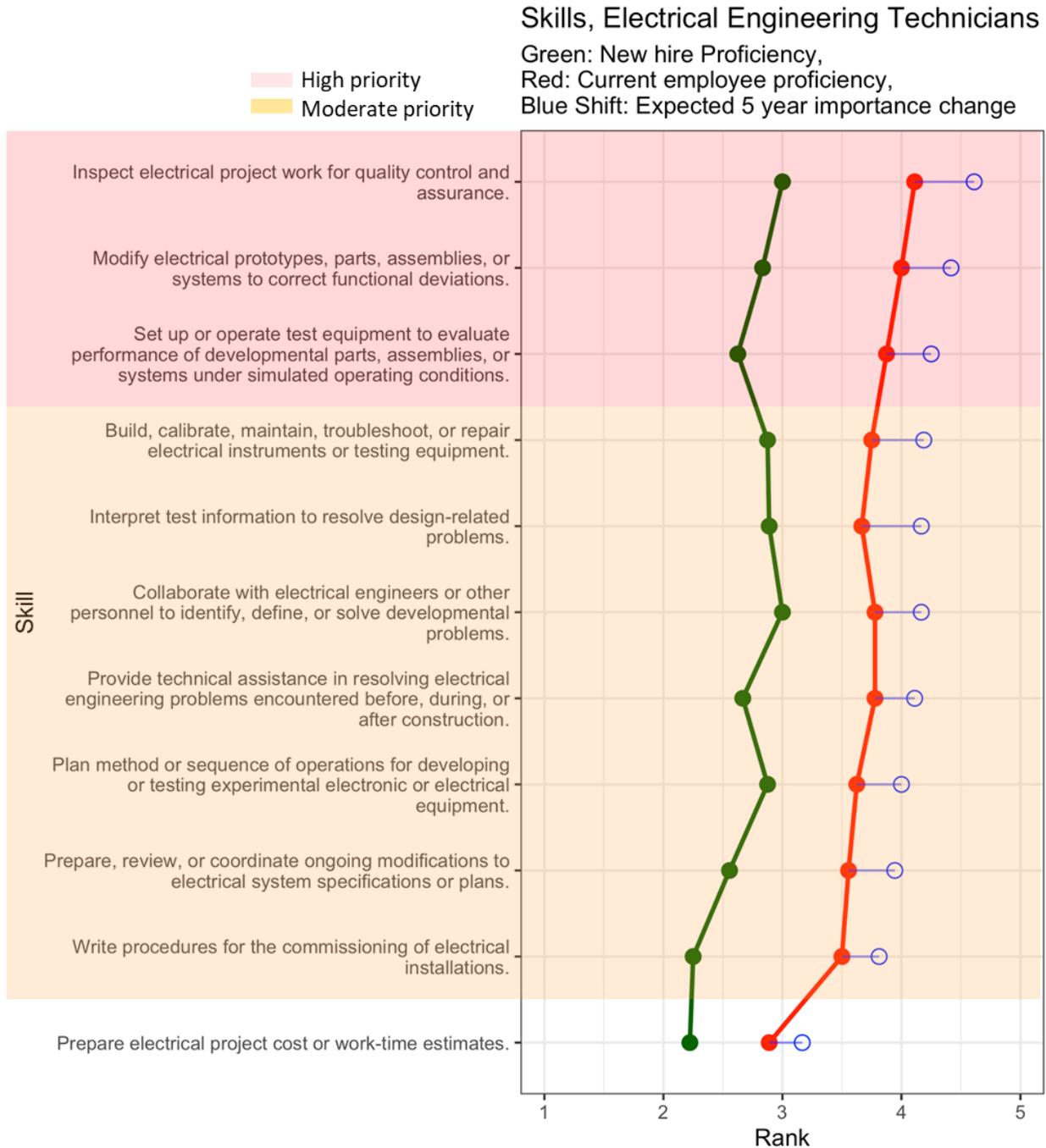


Figure 9. The gaps and expected future importance of skills for electrical engineering technicians are shown with high priority skills highlighted in red and moderate priority skills highlighted in orange.

Table 7. Recommended changes in the training of electrical engineering technicians in the robotics industry. The orange skills are those that are ranked as moderate priority and therefore have a skill gap and are also important in the future.

Recommendation	Skill	Full Skill Description
Emphasize training on...	Diagnose and resolve process or product problems	Inspect electrical project work for quality control and assurance.
		Modify electrical prototypes, parts, assemblies, or systems to correct functional deviations.
		Set up or operate test equipment to evaluate performance of developmental parts, assemblies, or systems under simulated operating conditions.
Improve training on...	Collaborate to improve design or troubleshoot problems	Provide technical assistance in resolving electrical engineering problems encountered before, during, or after construction.
		Collaborate with electrical engineers or other personnel to identify, define, or solve developmental problems.
	Manage electrical system specifications	Prepare, review, or coordinate ongoing modifications to contract specifications or plans.
		Write procedures for the commissioning of electrical installations.
	Build and maintain electrical instruments or testing equipment	Build, calibrate, maintain, troubleshoot, or repair electrical instruments or testing equipment.
	Develop and execute standard testing procedures	Interpret test information to resolve design-related problems.
		Plan method or sequence of operations for developing or testing experimental electronic or electrical equipment.
	Maintain training/evaluate training on...	Estimate project or process cost

Industrial Engineering Technician

Survey responses for industrial engineering technicians are shown in Figure 10. Recommendations for training of industrial engineering technicians based on these results are summarized in Table 8.

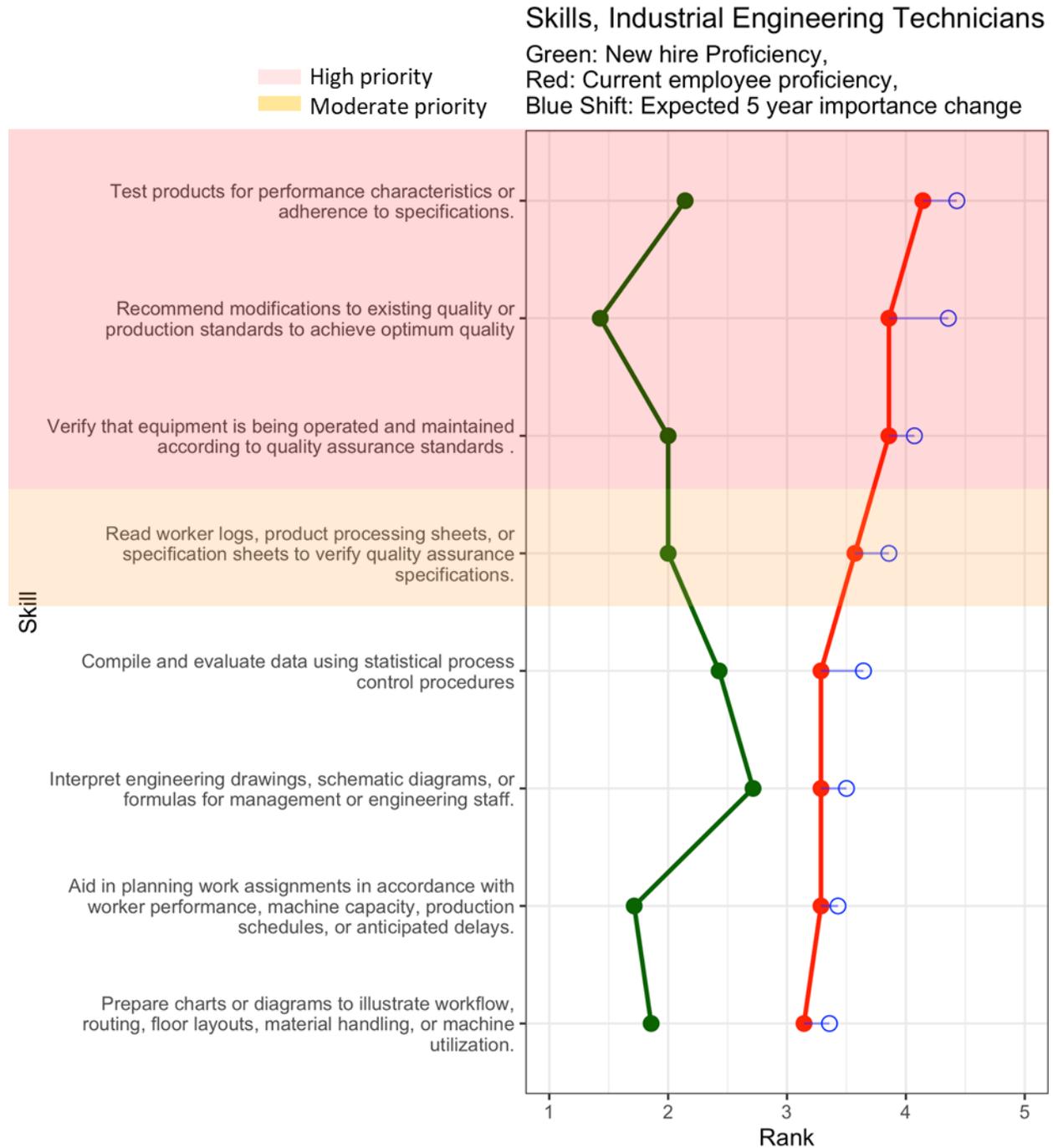


Figure 10. The gaps and expected future importance of skills for industrial engineering technicians are shown with high priority skills highlighted in red and moderate priority skills highlighted in orange.

Table 8. Recommended changes in the training of industrial engineering technicians in the robotics industry. The red skills are those that are high priority with a large gap and high importance in the future. The orange skills are those that are ranked as moderate priority and therefore have a skill gap and are also important in the future.

Recommendation	Skill	Full Skill Description
	Recommend operational & procedural changes	Recommend modifications to existing quality or production standards to achieve optimum quality
	Maintain product and process quality assurance standards	Test products for performance characteristics or adherence to specifications.
		Verify that equipment is being operated and maintained according to quality assurance standards.
Improve training on...		Read worker logs, product processing sheets, or specification sheets to verify quality assurance specifications.
Maintain training/evaluate training on...	Analyze and respond to process data	Compile and evaluate statistical data to determine and maintain quality and reliability of products.
	Communication with engineering and management	Prepare charts or diagrams to illustrate workflow, routing, floor layouts, material handling, or machine utilization.
		Interpret engineering drawings, schematic diagrams, or formulas for management or engineering staff.
	Recommend operational & procedural changes	Aid in planning work assignments in accordance with worker performance, machine capacity, production schedules, or anticipated delays.

CNC Tool Operator

Survey responses for CNC tool operators are shown in Figure 11. Recommendations for training of CNC tool operators based on these results are summarized in Table 9.

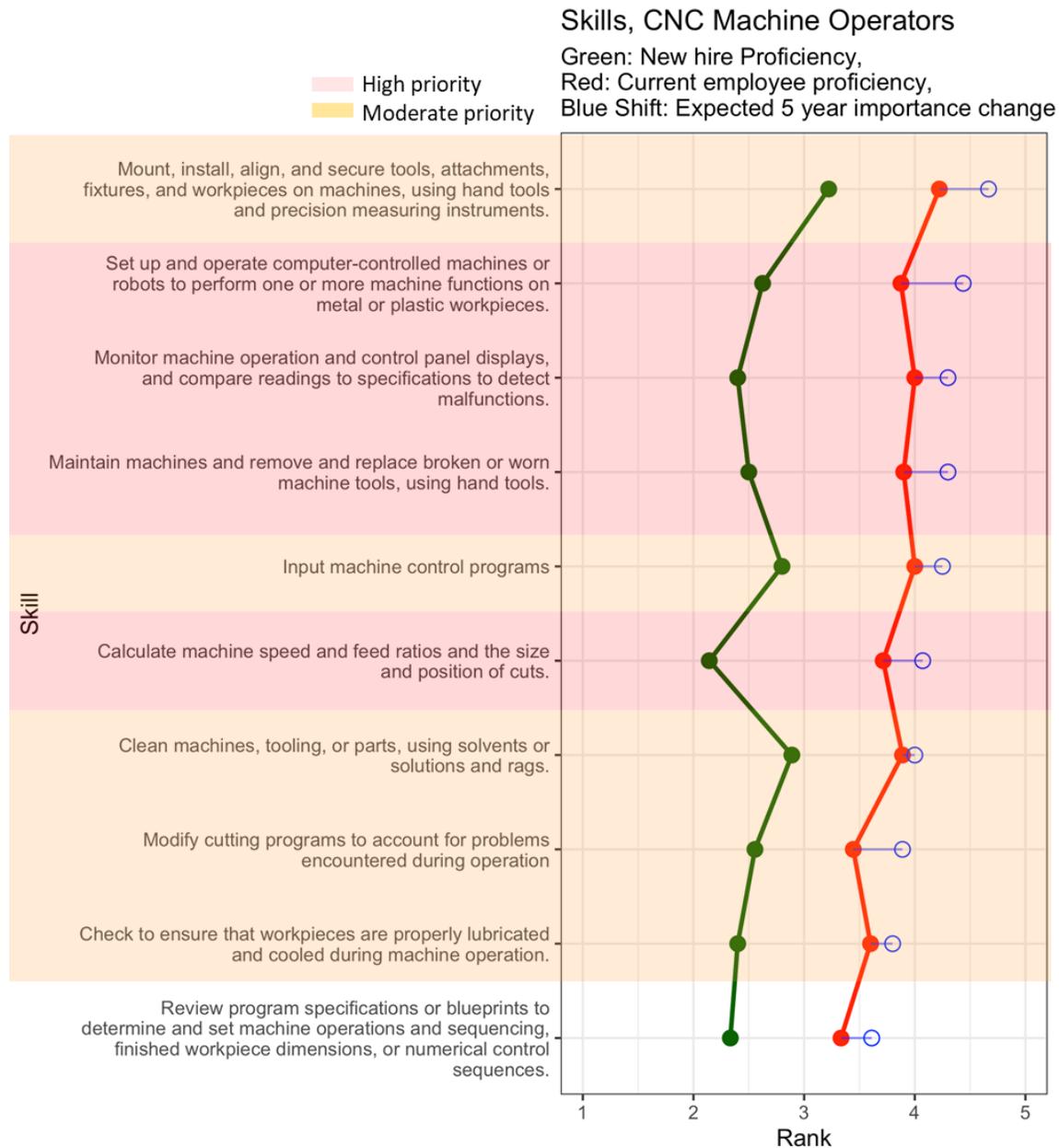


Figure 11. The gaps and expected future importance of skills for CNC tool operators are shown with high priority skills highlighted in red and moderate priority skills highlighted in orange.

Table 9 Recommended changes in the training of CNC tool operators in the robotics industry. The orange skills are those that are ranked as moderate priority and therefore have a skill gap and are also important in the future.

Recommendation	Skill	Full Skill Description
Emphasize training on...	Monitor and maintain machines.	Set up and operate computer-controlled machines or robots to perform one or more machine functions on metal or plastic workpieces.
		Monitor machine operation and control panel displays, and compare readings to specifications to detect malfunctions.
		Maintain machines and remove and replace broken or worn machine tools, using hand tools.
	Calculate machine speeds and feed ratios	Calculate machine speed and feed ratios and the size and position of cuts.
Improve training on...	Apply precision measuring instruments	Mount, install, align, and secure tools, attachments, fixtures, and workpieces on machines, using hand tools and precision measuring instruments.
	Machine operation and maintenance	Input machine control programs
		Clean machines, tooling, or parts, using solvents or solutions and rags.
		Modify cutting programs to account for problems encountered during operation
		Check to ensure that workpieces are properly lubricated and cooled during machine operation.
Maintain training/evaluate training on...	Assess specifications or blueprints	Review program specifications or blueprints to determine and set machine operations and sequencing, finished workpiece dimensions, or numerical control sequences.

Identifying the high priority skills gaps

Across all positions, there were 17 skills that were classified as high priority – exhibiting both high future importance and a significant skills gap (i.e., the gap between the proficiency of new hires are the level of proficiency needed in the future). These skills and their skills gap are shown in Figure 12 where the blue dot indicates the future proficiency needed and the green dot represents the proficiency of current new hires.

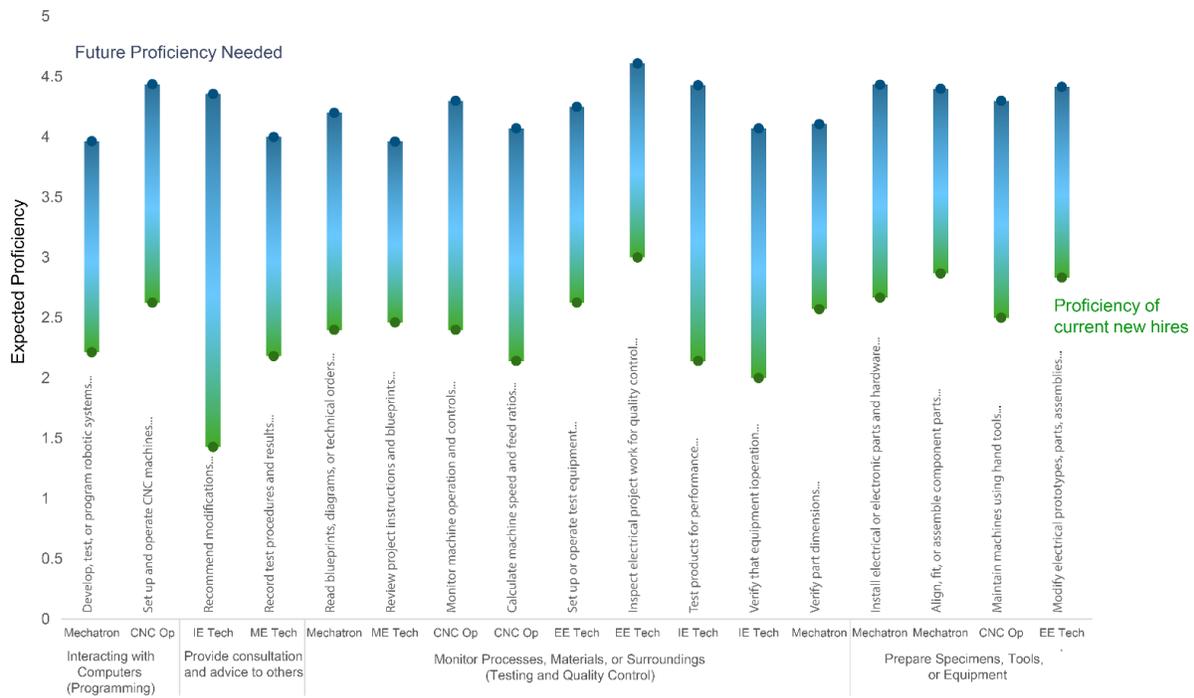


Figure 12 High priority skills across all positions studied in the robotics industry. The green dot represents the proficiency of current new hires and the blue dot represents the future proficiency needed for the middle-skilled level.

These high priority skills are all associated with one of four generalized skill categories. These are:

- Interacting with computers (programming)
- Provide consultation and advice to others
- Monitor processes, materials, or surroundings (testing and quality control)
- Prepare specimens, tools, or equipment

Notably, this same set represent four of the five most important generalized skills (see section Identifying Important Common Skills). Discussions during the interviews regularly emphasized the importance of computer skills and troubleshooting (i.e. provide consultation... and monitor processes ...) for technicians in this emerging field.

Emerging and Human skill needs

Along with assessing current technical skills for each position, respondents also were asked to consider the importance of specific emerging and human skills for middle-skilled technical workers. Emerging skills were identified through two approaches – review of the workforce development literature and analysis of the BGLI database.

As was noted earlier, delays in access to the BGLI database precluded results from that database from informing the design of the interview template. As such, here we describe the analysis of the BGLI database for the robotics industry first and then present the results of the industry survey on the importance of the emerging skills identified in the literature (see Figure 14).

Real-Time Skills Analysis from Burning Glass Labor Insight™ (BGLI)

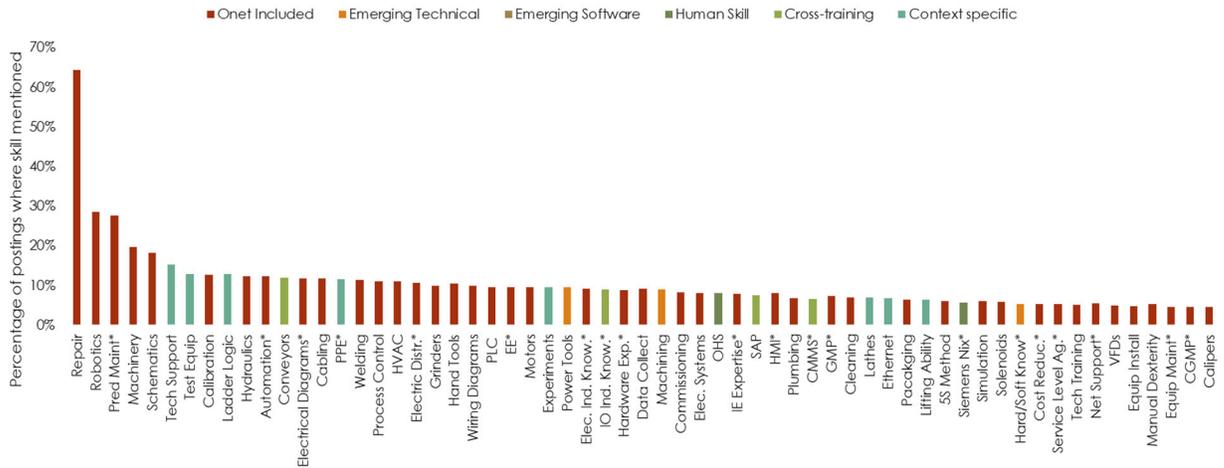
The comparison of the two datasets found that ~70%⁵ of the skills and technologies highlighted by the BGLI database were present within the O*NET characterization of the focal occupations. Those that were not present were classified as one of the following:

- Emerging skill, tool, or technology: The real-time database captured an emergent skill or technology that has not been updated in the O*NET database.
- Value-added human skill: A human skill that is not specifically captured in the survey conducted here or within the O*NET database. (e.g., customer service or sales skills for technicians) but that is valuable in this industry.
- Value-added cross-training: Skills that are outside of the definition of the specified occupation but which represent valuable additional skills for some employers. (e.g., industrial engineering skills for mechanical engineering technicians)
- Context-specific skills: Skills that are valuable to particular employers because of the specifics of their operations, market, or other business conditions (e.g., HVAC or packaging design skills for mechanical engineering technicians)

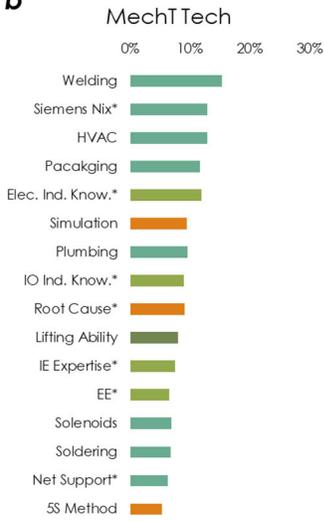
The real-time labor market intelligence analytics data complements the O*NET database because it enables the identification of emerging trends in technical skills and knowledge and software skills and technologies in the robotics industry. For each of the relevant positions present in BGLI, the most frequently observed skills are shown in Figure 13. Specifically, Figure 13a shows all skills present in at least 5% of postings for the mechatronics technicians including both those included in the O*NET framework (dark red columns) and those that are not. To better focus on uniquely identified skills, Figure 13b, c, d, and e plot only the skills absent in O*NET for mechatronic (MechT), mechanical (ME), industrial (IE), and electrical/electronic (EE) technicians.

⁵ An average of 71% across both the keyword and employer-based approach in at least 5% of postings for all four positions

a



b



c



d



e

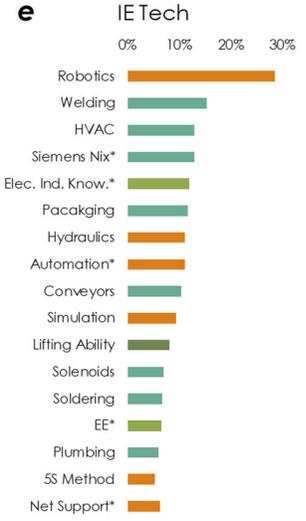


Figure 13 The most frequently observed skills in the BGLI for mechatronics technicians categorized as ONET included, emerging technical, emerging software, human skill, cross-training, or context specific(a). The skills that were not found in ONET are also shown for each of the positions in b-e.

*Full skill names include: Predictive/Preventative Maintenance, Programmable Logic Controller Programming, Electrical Diagrams/Schematics, Hardware Experience, Electrical Distribution Systems, Computer Hardware/Software Knowledge, Service Level Agreement, Siemens Nixdorf Hardware, Electronics Industry Knowledge, Industrial Operations Industry Knowledge, Industrial Engineering Expertise, Electrical Engineering, Root Cause Analysis, Network Support, Automation Systems, Operational Cost Reduction, Computerized Maintenance Management Systems, Human Machine Interface, Personal Protective Equipment (PPE).

For mechatronic technicians, several emerging technical skills were found in more than 5% of postings including hydraulics, simulation, root cause analysis, and the 5S Methodology. Robotics and automation were prevalent emerging skills for mechanical, electrical, and industrial engineering technicians. These results agree with interview findings: as automation technologies become more pervasive, engineering technicians of all types will be expected to have robotics knowledge and training. In addition, as human roles change in the automated manufacturing environment, technicians may be

to simulate that system. The BGLI database also highlights emerging software skills that are common across all four positions including Python and Linux. It is important to note that emerging here does not mean that the software is itself new, but rather that competency with that software appears to be an emerging need for engineering technicians. Interview respondents also emphasized the need for curriculum focused on programming and debugging.

A common human skills across the positions includes lifting ability. Learnings from the interviews also suggested that for deployment and installation technician roles in particular, customer-facing communication skills are growing in importance since many such individuals represent the firm at customer sites. Cross-training skills that are common and complement conventional disciplinary training include knowledge of other industries such as industrial, electrical, industrial operations, and others.

Emerging and Human Skill Interview Results

Because importance was evaluated identically for both emerging and human skills, these results are presented together in Figure 14 and summarized in Table 10. Blue text is used to distinguish human from technical skills.

Prospective New Hires, Ability Importance
Abilities in descending composite rank order

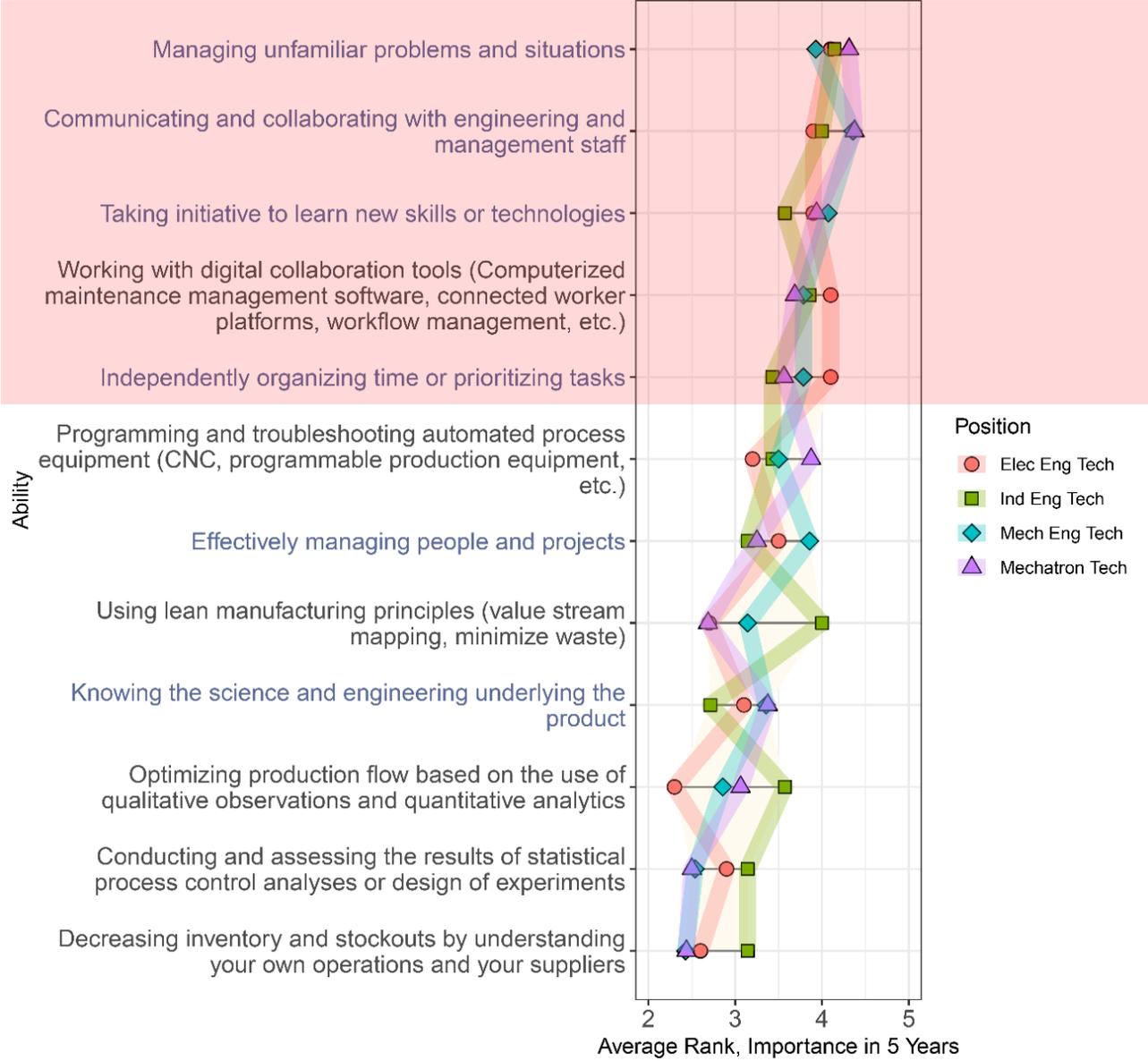


Figure 14 The expected importance of emerging technical and human skills was ranked as much less important than now, less important than now, as important than now, more important than now, and much more important than now. The first five skills, highlighted in red, are those that are important across all the positions studied. The remaining skills have varying levels of importance that are specific to each position. Skills in blue represent emerging human skills.

Table 10. Recommendations for emerging skill training across all technicians (red) and for job-specific roles.

Emphasize training for...	Full Skill Description
All occupations	Communicating and collaborating with engineering and management staff
	Managing unfamiliar problems and situations
	Taking initiative to learn new skills or technologies
	Working with digital collaboration tools (Computerized maintenance management software, connected worker platforms, workflow management, etc.)
	Independently organizing time or prioritizing skills
<ul style="list-style-type: none"> • Mechatronics Technicians • CNC Tool Operators • Electrical Engineering Technicians 	Programming and troubleshooting automated process equipment (CNC, programmable production equipment, etc.)
<ul style="list-style-type: none"> • Mechanical Engineering Technicians • Chemical/Materials Technicians • Electrical Engineering Technicians 	Effectively managing people and projects
<ul style="list-style-type: none"> • Chemical/Materials Technicians 	Knowing the science and engineering underlying the product
<ul style="list-style-type: none"> • Industrial Engineering Technicians 	Using lean manufacturing principles (value stream mapping, minimize waste)
<ul style="list-style-type: none"> • Industrial Engineering Technicians 	Optimizing production flow based on the use of qualitative observations and quantitative analytics
<ul style="list-style-type: none"> • Chemical/Materials Technicians 	Conducting and assessing the results of statistical process control analyses or design of experiments
Not relevant for technicians	Decreasing inventory stockouts by understanding your own operations and your suppliers

These results indicate that all technician training programs for robotics should put an emphasis on:

- 1) communicating and collaborating – including the use of digital tools;
- 2) managing unfamiliar problems and situations; and
- 3) taking initiative to learn new skills or technologies.

While some respondents believed these skills can be hard to teach in a classroom, many suggested that these skills can be gained through hands-on experience in a lab class setting or through apprenticeship or internship programs. Many respondents noted that competency in skills such as lean manufacturing, optimizing production flow, statistical process control, and decreasing inventory and stockouts would be beneficial, but are expected more for engineers than technicians.

Out of all the emerging skills, respondents emphasized troubleshooting as a skill central to all technician jobs. There is a higher expectation for engineering technicians compared with tool operators. Every firm indicated that they assess the ability to troubleshoot during interviews through behavioral questions, past experiences, and timed Berke assessments of rapid problem solving. Respondents shared that they look for technicians to explain how they would approach a problem and ask questions about that problem. Many firms explained that they have checklists to aid technicians in the debugging process. If curriculum were updated to include opportunities to practice troubleshooting problems or debugging with checklists, this could help better prepare students for the expectations of a technician job.

Critical thinking skill needs

When trying to define what is meant by critical thinking, one definition is “the ability to analyze evidence and facts to form a judgment” (Gambrell 2005). More practically, we can classify these judgments with the following levels of critical thinking:

1. Perceiving the issue – What should I measure or observe to know that a problem exists?
2. Hypothesizing about problem cause – What might be causing the problem?
3. Developing a framework for hypothesis testing – How can I confirm my hypothesis?
4. Inferring whether tests confirm the hypothesis - Does the test suggest that my hypothesis was right?
5. Communicating the outcome – How (and to whom) do I report on what has happened?

Respondents were asked to identify what level of critical thinking is expected of technicians. Responses were grouped by Engineering Technician positions and All Other Technical Workers shown in Figure 15.

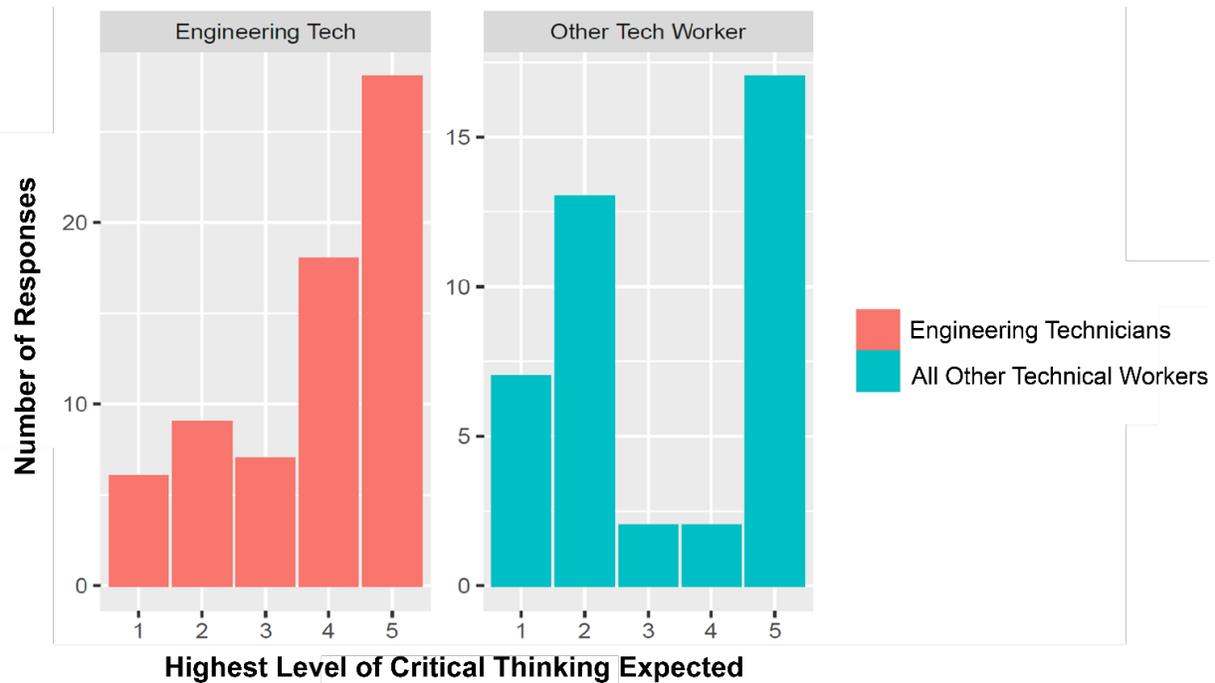


Figure 15. Respondents valued critical thinking skills for all occupations studied. However, most respondents expect a higher level of critical thinking in the 4-5 range for engineering technicians. While there are respondents that expect the highest level for all other technical workers as well, there is still a large percentage of respondents that only expect a level of 1-2.

Results indicate that the majority of engineering technicians (68%) are expected to have competency in nearly all aspects of critical thinking (perceiving, hypothesizing, testing, and interpreting testing) and an additional 15% are also expected to communicate the outcome of the process. Results for other technical workers were split, with about half (48%) expected to only perceive the issue and hypothesize a cause while most of the rest are expected to master all aspects of critical thinking.

Many firms indicated that critical thinking skills are becoming essential, particularly for engineering technician positions. Because technicians are a part of the front line, being able to critically think and spot patterns of error is very important. Respondents explained that being able to determine the root cause of a problem and then communicate the problem to a larger team makes workers more valuable. One example of a judgement that technicians need to regularly make is when to get help. If technicians had training in identifying problems and knowing what information needs to be communicated upstream to help with decision making, firms would be able to improve their overall productivity.

Respondents indicated that two important critically thinking areas include looking for defects and eliminating waste. For cases of failure on certain parts, technicians are expected to collect data on the critical part, document what happened and when, and work with an engineer to figure out the cause of failure. One suggestion was to include

the Lean Sigma Define, Measure, Analyze, Improve, Control (DMAIC) process in training for technicians (ASQ 2021). Virtual reality (VR) technology could also be leveraged to practice critical thinking by developing manufacturing simulations.

Identifying Important Common Skills

To understand the skills needed broadly at the middle-skill occupation level, the research team has identified skills that are both shared (common) and important across multiple occupations to enable training programs to be relevant for companies across the robotics supply chain. Figure 16 shows the ten highest weighted average importance scores for the general task/skill (GTS) level ranked from highest to lowest.

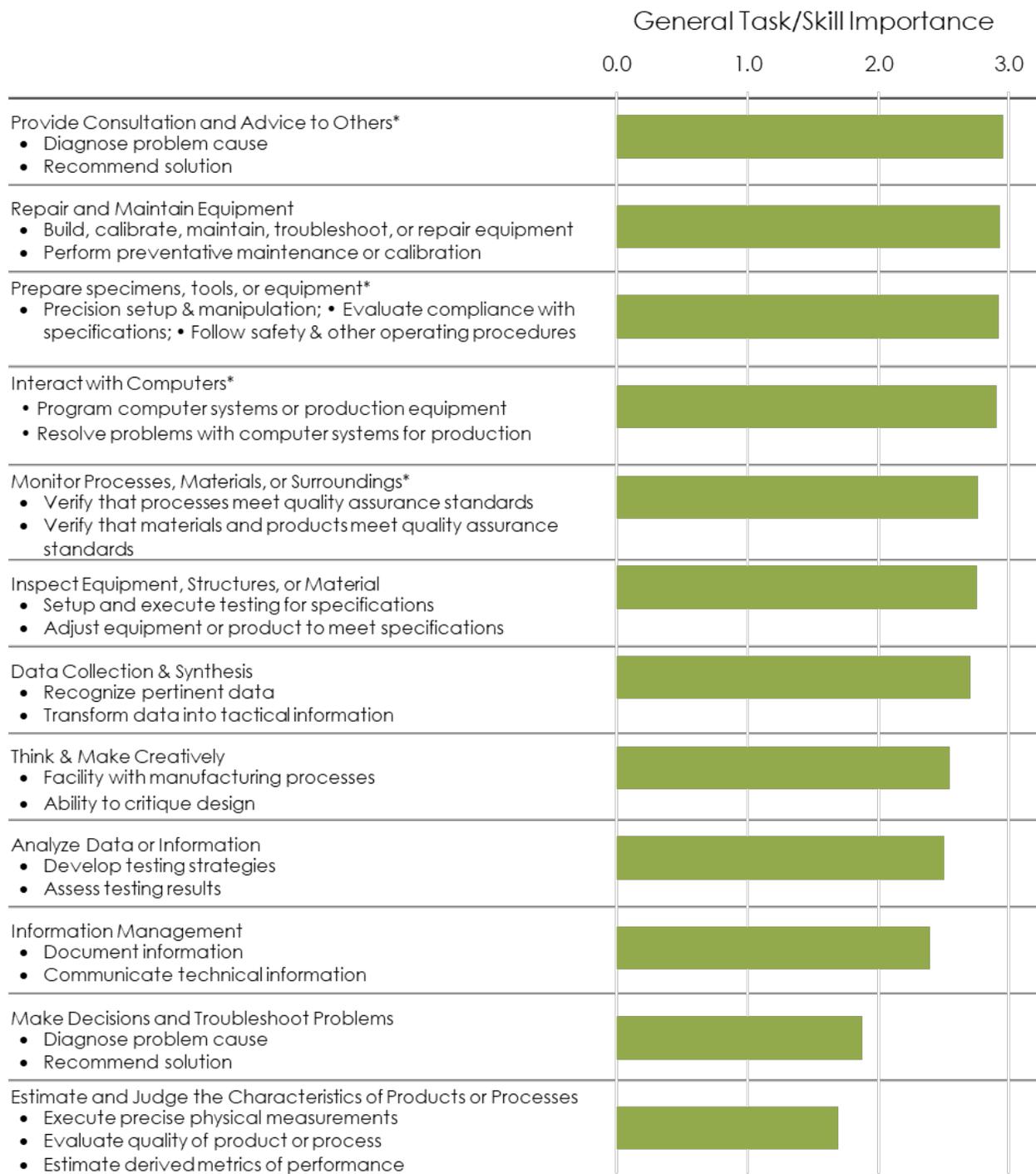


Figure 16 General Task/Skill (GTS) are classes that include many related specific skills. Here relevant GTS are ranked by weighted average importance of the specific skills within that class. Only GTS that are shared across at least two occupations are labeled as common and, therefore, included in this figure. Asterisks indicate skills that have a critical gap and are of significant importance.

The top three ranked common skills include

- 1) provide consultation and advice to others,
- 2) repair and maintain equipment, and
- 3) prepare specimens, tools or equipment.

All of these skills involve an understanding of the system as well as the ability to communicate with other members of the team. In addition, many of the remaining common skills (e.g. interacting with computers, monitoring processes, inspecting equipment) involve an understanding of quality assurance, critical thinking, and troubleshooting abilities. Table 11 to Table 13 provide details on the underlying specific skills associated with these GTS. Details for all GTS are provided in the appendix.

Details on Common Skills

Table 11 shows the underlying categorization and score detail for the two highest ranked GTS, "Provide Consultation and Advice to Others" and "Repair and Maintain Equipment." The specific skills in the provide consultation and advice category include cognitive activities that require critical thinking such as "review new product plans and make recommendations" or "recommend modification to existing quality standards." There are also communication skills that are required such as "providing technical assistance." These skills were important and common for electrical engineering technicians and industrial engineering technicians. For repairing and maintaining equipment, there are physical skills required such as "using hand tools" or "build, calibrate, maintain..." But, there are also skills that require troubleshooting skills such as "troubleshoot or repair equipment." This skillset was especially important for electrical engineering technicians, electro-mechanical and mechatronics technicians, and CNC tool operators.

Table 11. Details of skill importance for General Task/Skill “Provide Consultation and Advice to Others” and “Repair and Maintain Equipment” and their sub classes and skills. (-nr- indicates insufficient responses to report a meaningful average).

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Photonic T	Ind Eng T	ElecEng T	Chemical T	MechEng T	MechaTron T	CNC Oper	Machinists
Provide Consultation and Advice to Others	3.0	Advise others on the design or use of technologies.	3.1	Provide technical assistance in resolving electrical engineering problems encountered before, during, or after construction.	3.1			X					
		Advise others on business or operational matters.	2.8	Recommend modifications to existing quality or production standards to achieve optimum quality	3.2		X						
				Review new product plans and make recommendations for material selection, based on design objectives such as strength, weight, heat resistance, electrical conductivity, and cost.	-nr-								
Repairing and Maintaining Equipment	2.9	Repair tools or equipment.	3.2	Maintain machines and remove and replace broken or worn machine tools, using hand tools.	3.2							X	
		Maintain electronic, computer, or other technical equipment.	3.1	Build, calibrate, maintain, troubleshoot, or repair electrical instruments or testing equipment.	3.1			X					
		Maintain tools or equipment.	2.8	Repair, rework, or calibrate hydraulic or pneumatic assemblies or systems to meet operational specifications	2.5						X		

Table 12 shows the details of the scoring for the third highest ranked GTS, “Prepare specimens, tools, or equipment.” This skillset requires physical skills such as preparing solutions, using hand tools, assembling parts, and operating equipment. GTS was found in the electrical engineering technicians, chemical and materials technicians, CNC tool operators, mechanical engineering technicians, and electro-mechanical and mechatronics technicians. Most of these skills require the physical workmanship to maintain and service equipment, the cognitive understanding of how the machine functions, and troubleshooting skills to understand how to address malfunctions.

Table 12. Details of skill importance for General Task/Skill "Prepare specimens, tools, or equipment" and its sub classes and skills. (-nr- indicates insufficient responses to report a meaningful average).

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Photon T	Ind Eng T	ElecEng T	Chemical T	MechEng T	MechaTron T	CNC Oper	Machinists
Prepare specimens, tools, or equipment	2.9	Prepare specimens or materials for testing.	3.7	Prepare chemical solutions for products or processes, following standardized formulas, or create experimental formulas.	-nr-				X				
		Set up equipment.	3.5	Mount, install, align, and secure tools, attachments, fixtures, and workpieces on machines, using hand tools and precision measuring instruments.	3.6							X	
				Set up and conduct chemical experiments, tests, and analyses, using techniques such as chromatography, spectroscopy, physical or chemical separation techniques, or microscopy.	-nr-				X				
		Install commercial or production equipment.	3.3	Install electrical or electronic parts and hardware in housings or assemblies, using soldering equipment and hand tools.	3.3						X		
		Assemble equipment or components.	3.3	Align, fit, or assemble component parts, using hand or power tools, fixtures, templates, or microscopes.	3.4						X		
				Build, calibrate, maintain, troubleshoot, or repair electrical instruments or testing equipment.	3.1		X						
		Disassemble equipment.	3.2	Maintain machines and remove and replace broken or worn machine tools, using hand tools.	3.2							X	
		Adjust equipment to ensure adequate performance.	2.7	Repair, rework, or calibrate hydraulic or pneumatic assemblies or systems to meet operational specifications	2.5						X		
		Fabricate devices or components.	1.9	Fabricate and assemble new or modified mechanical components for products such as industrial machinery or equipment, and measuring instruments.	2.6					X			
				Operate drill press, grinders, engine lathe, or other machines to modify or to fabricate components.	2.1					X			
				Operate metalworking machines to fabricate housings, jigs, fittings, or fixtures.	0.9						X		

Table 13 details the final important common skills "Interact with Computers" and "Monitor Processes, Materials, or Surroundings." The GTS for interacting with computers is estimated for electro-mechanical and mechatronics technicians and CNC tool operators. This skillset involves critical thinking on the part of the worker to not only set up and operate computer systems, but to also troubleshoot or debug programs. The worker must understand how the control programs work and how to test or program robotic systems. The final skill is common and important for industrial engineering technicians and CNC tool operators. The skillset of monitoring processes includes critical thinking skills and an understanding of quality assurance including "verifying quality assurance specifications" or "compare readings to specifications to detect malfunctions."

Table 13. Details of skill importance for General Task/Skill "Interact with Computers" and "Monitor Processes, Materials, or Surroundings" and its sub classes and skills. (-nr- indicates insufficient responses to report a meaningful average).

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Photonic T	Ind Eng T	ElecEng T	Chemical T	MechEng T	Mechatron T	CNC Oper	Machinists	
Interacting With Computers	2.9	Program computer systems or production equipment.	2.9	Input machine control programs	3.2							X		
				Set up and operate computer-controlled machines or robots to perform one or more machine functions on metal or plastic workpieces.	3.0							X		
				Modify cutting programs to account for problems encountered during operation	2.6								X	
				Develop, test, or program automated production equipment or other robotic systems.	2.5							X		
Monitor Processes, Materials, or Surroundings	2.8	Monitor operations to ensure adequate performance.	2.9	Verify that equipment is being operated and maintained according to quality assurance standards .	2.9		X							
				Monitor equipment operation.	2.8							X		
				Check to ensure that workpieces are properly lubricated and cooled during machine operation.	2.4							X		
				Monitor operations to ensure compliance with regulations or standards.	2.6		X							

Results Summary

Workforce needs were identified for middle skilled technical workers in the robotics industry through semi-structured interviews with operations managers from thirty-one firms throughout the New England region and analysis of real-time labor market intelligence databases on industry hiring. The interviews were focused on middle-skilled technical occupations (except for information technology occupations). The goal of the interviews was to characterize trends in demand, hiring challenges, training gaps, and the importance of specific technical and human skills relevant to the robotics industry.

Results demonstrate increasing demand for middle-skilled technical workers and highlight skills gaps among these workers. There is strong growth expected for mechatronics technicians, electrical and mechanical engineering technicians, and robotics installation and deployment technicians. Interestingly, of the occupations studied here, robotics deployment technicians are expected to see the largest growth in number of positions and openings within the United States robotics industry.

To further characterize workforce demand in this sector, we made use of data from the US Bureau of Labor Statistics, market intelligence reports, and survey responses to project both anticipated positions and openings. We estimate middle-skilled positions within this industry to grow from around 4,000 today to 7,500 by the end of the decade. This translates to over 10,000 cumulative openings for middle skilled technical workers or around 870 new middle-skilled workers per year. Assuming a typical training program graduates about 15 students per year, the US would need nearly 60 programs to meet the demand of this industry. In a Massachusetts context, we estimate around 275 positions today growing to 470 positions in 2030. This translates to about 54 middle-skilled openings per year, resulting in about 4 programs needed for training middle-skilled workers in the state.

In addition to indicating strong growth for many occupations, respondents also noted significant hiring challenges and a need for extensive on-the-job training for new hires. There are three occupations that exhibited both hiring challenges and training gaps:

- Electro-Mechanical and Mechatronics Technicians
- Chemical/Materials Technicians
- Maintenance and Support Technicians

We highlight the specific technical skills that are both increasingly important and exhibit skills gaps for five occupations: mechatronics technicians, electrical engineering technicians, mechanical engineering technicians, industrial engineering technicians, and CNC tool operators.

Emerging and human skill importance was also evaluated for each position including a critical thinking needs assessment. An emphasis on two emerging technical skills is recommended for technician training across all positions:

- working with digital collaboration tools and
- programming and troubleshooting automated process equipment.

Human skills are also growing in importance for technicians in the robotics industry. In particular, the following skills should be included in training:

- Communicating and collaborating with engineering and management staff
- Managing unfamiliar problems and situations
- Taking initiative to learn new skills or technologies
- Independently organizing time or prioritizing skills

Many firms indicated that critical thinking skills are becoming essential, particularly for engineering technician positions. Because technicians are a part of the front line, being able to critically think and spot patterns of error is very important. Results indicate that the majority of engineering technicians (68%) are expected to have competency in nearly all aspects of critical thinking (perceiving, hypothesizing, testing, and interpreting testing) and an additional 15% are also expected to communicate the outcome of the process. Results for other technical workers were split, with about half (48%) expected to only perceive the issue and hypothesize a cause while most of the rest are expected to master all aspects of critical thinking.

Because the interviews focused on skills derived from work activities described in the Bureau of Labor Statistics O*Net dataset, it was possible to not only identify job-specific skills but also to use the taxonomy within that dataset to aggregate survey responses to more generalized classes of skills (referred to as General Task/Skill, GTS).

Looking across all middle-skilled positions, the top five generalized skills that are expected to be the most important for middle-skilled workers in the robotics industry are:

- Provide Consultation and Advice to Others*
- Repair and Maintain Equipment
- Prepare specimens, tools, or equipment*
- Interact with Computers*
- Monitor Processes, Materials, or Surroundings*

Four of these skills categories (marked with an asterisk) were also flagged as being associated with a significant gap between the skill level of incoming workers and the skill level required by industry.

Based on this analysis it is clear that it would be valuable to increase emphasis within engineering technician training on skills that aid technicians in providing consultation and advice to others. This includes both an understanding of the entire system or process as well as verbal and written communication skills to explain the details of the problem and potential solutions. Repairing and maintaining equipment entails building, calibrating, and troubleshooting equipment malfunctions to minimize downtime. Preparing

specimens, tools, or equipment involves the ability to follow operating procedures and safety guidelines and attention to detail. Technicians in the robotics industry are also expected to interact with computers including programming computer and production systems and debugging code to resolve technical problems. In addition to the ability to repair equipment, the skill of monitoring processes, materials, or surrounding is also common across positions. This skill requires knowledge of quality, the ability to collect and interpret data on process or product, attention to detail, and knowledge of operating safety and settings.

For middle-skilled workers in the robotics industry, the analysis of generalized skills points to the growing importance of the abilities to program, operate, and troubleshoot equipment, to collect and interpret data, and to communicate that interpretation to others.

Taken together, these results demonstrate both the increasing number of technical careers in the robotics industry and the presence of key opportunities to improve the training and skills development of those pursuing these occupations.

Appendix

Literature review and gap analysis

Past efforts to characterize skills gaps and fulfill workforce needs have been successful in increasing employment opportunities specifically for middle-skilled workers. In Pennsylvania, a National Science Foundation (NSF) grant provided funding to develop community college programs in the area of nanofabrication (Hallacher, Fenwick, and Fonash 2002) through professional development workshops for educators and new curricula for students. Through these efforts, community college graduates from targeted nanofabrication programs received more than seven job offers on average upon graduation. There were also regional benefits of new nanofabrication facilities locating to Pennsylvania as a result of the increased workforce and skill development of Pennsylvania community college graduates. In an NSF funded workshop for additive manufacturing (AM), stakeholders evaluated the current state, workforce needs, and future trends to inform research and education and training for the upcoming workforce (Huang et al. 2015). Their findings suggest the university-community college partnership model can enable a well-trained AM workforce through sharing of lectures, knowledge via educator workshops, web resources, and laboratory spaces for hands-on training. Participants in the workshop recommended future funding opportunities through America Makes, the NSF, and other federal agencies for AM education and curricula development. With support for feeder programs, a stable workforce of well-trained, low-cost, entry-level technicians will continue to grow (Foy and Iwaszek 1996). In addition to curricula development, internship opportunities will also be necessary for the up-and-coming workforce to obtain the on-the-job experience necessary to fill these critical gaps (Hardcastle and Waterman-Hoey 2010).

While curricula have been developed for emerging manufacturing areas in the past (e.g. nanofabrication), this is the first development of a roadmap method to assess workforce gaps and needs across several advanced manufacturing industries. This research provides a method to classify emerging advanced manufacturing industries, identify companies within the industry, and leverage industry expertise to inform workforce development needs. In BLS, these emerging manufacturing industries are organized broadly, and as a result, the industries are not immediately apparent. To address these limitations, we've developed a systematic, data-driven method for classifying advanced manufacturing industries and an industry stakeholder informed education roadmap on current priority and future accelerating jobs and training needs. The education roadmap will provide recommendations for community college, certificate programs, and instructors on how to upgrade their photonics curricula and matriculate more competitive technician candidates, for targeted hiring in photonics industry clusters across the US. This method is performed in four steps: 1) classification of emerging advanced manufacturing industries, 2) survey development leveraging industry expertise, 3) survey assessment by experts, and 4) survey distribution, response analysis

and recommendations. To demonstrate the method for classifying and assessing employment needs for an advanced manufacturing industry, the method is applied to a case study of the photonics industry.

Detailed Methods

To characterize workforce needs within advanced manufacturing industries we have relied primarily on interviewing firms within that industry. Development and deployment of the semi-structured interview followed a process involving four major steps.



Discern emerging advanced manufacturing industries

The discernment process aims to identify a sufficiently large sample of firms that are representative of the advanced manufacturing sector of interest and to identify how these firms are currently classified in some relevant industrial classification system. This classification system will be referred to as the discernment system. This information will play two roles in subsequent analyses. First these firms will be the target of surveys and interviews. Second, the classifiers associated with these firms will be used to estimate employment intensity from BLS databases.

The first step in this classification process was to identify firms that are representative for the industry of interest. We refer to these firms as archetypes. This is an inherently manual, expert-based process. For the robotics, archetype firms were identified through a number of methods, including querying member listing from relevant professional associations⁶ and expert elicitation. Once archetypes were identified, they were queried within the discernment system. The most common economic activity type (EAT) codes associated with those firms within the discernment system were cataloged. This set of codes serves as one definition of our industry of interest and were used to identify a larger set of similar firms.

⁶ In this case, we specifically queried the membership roster of ARM (Advanced Robotics for Manufacturing) a Manufacturing USA institute based in Pittsburgh, PA.

To leverage data catalogued by the US BLS, firms must be identified using the North American Industrial Classification System (NAICS) (Dalziel 2007). If the discernment system is not NAICS (as it was not in our case study here), then it is necessary to create an empirical mapping between the two systems. Here we do this by using the discernment system to identify a larger set of firms of the same type as the archetypes and then identifying the prevailing NAICS codes used to characterize those firms.

The North American Industrial Classification Systems (NAICS)

Industry classification systems reflect a country's economic output, trade, and employment (Dalziel 2007). The NAICS is a framework that is used widely for firm classification. NAICS was developed in 1997. It captures a large number of business types including those in the service industry (BLS). In the NAICS system, firms are identified using their production processes and the codes are updated every five years to reflect changes in industry titles and descriptions. The industries and sectors are classified with two to six digits, where the higher number of digits represents a greater detailed classification of the industry.

While the NAICS system may be more representative than its predecessor, the SIC system, many researchers have found limitations in classifying industries based on their production processes (Kile and Phillips 2009). For instance, Dalziel (2007) explains that eight non-diversified communications equipment manufacturers are classified in four separate industries and two separate sectors despite being major competitors. Other limitations include addressing the rapid changes in technology advancements. While there are many different types of software companies, all firms that develop software are classified with the same code, 511210, Software Publishers (Dalziel 2007). In classifying emerging industries, such as those in the advanced manufacturing space, it can be challenging to identify the boundaries of the industry and assign a NAICS code that is accurately representative of a firm's activities. For example, when searching the NAICS database for "photonics", the NAICS code assigned is 541715, Research and Development in the Physical, Engineering, and Life Sciences (except Nanotechnology and Biotechnology). Although photonics can be classified under this code, botany and agricultural research also share this classification. This shows yet another limitation of the NAICS system; the NAICS codes are often too broad to capture the specifics of an emerging industry. As a result, it can be difficult to capture the current employment statistics for an advanced manufacturing industry and understand the existing workforce gaps.

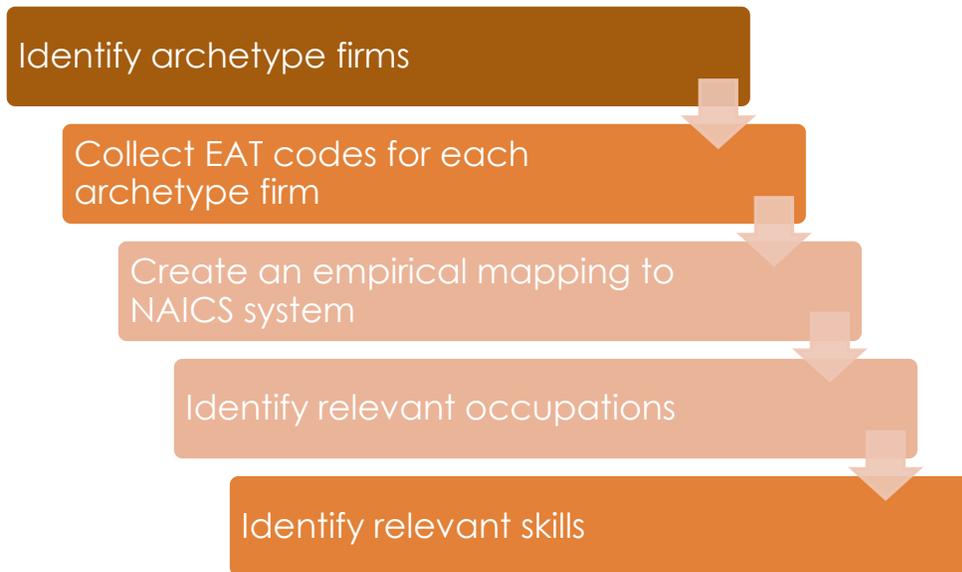


Figure 17 5-step process for discerning emerging advanced manufacturing industries.

The global robotics industry is valued at \$23.67 billion growing to \$74 billion by 2026 (Mordor Intelligence 2021). Table 14 lists nine companies that were identified as archetypes for the robotics industry.

EAT codes for several industrial classification systems were collected for each archetype firm using the D&B Hoovers business database (Dun and Bradstreet 2020). Here we elected to use the D&B Hoovers Proprietary SIC 8-digit Code (SIC8) classification system (Cramer 2017), an expansion of the original SIC system, to discern the industry. Table 14 shows the SIC8 and NAICS EAT codes for the archetype firms. If a primary and secondary code are provided, both codes are listed. This process was repeated for all the archetype companies for the industry to help develop a description of the firms based on the industrial classification codes.

Table 14 Robotics industry classification archetype examples

Company	US Standard Industrial Classification – DB Hoovers Expanded Version (SIC8)	North American Industrial Classification System (NAICS)
Ascend Robotics	35359904 - Robotic conveyors	333922 - Conveyor and Conveying Equipment Manufacturing
Dynamic Robotic Solutions	35419913 - Robots for drilling, cutting, grinding, polishing, etc.	333517 - Machine Tool Manufacturing
Absolute Robot, Inc.	35429917 - Robots for Metal forming: pressing, extruding, etc.	333517 - Machine Tool Manufacturing
Symbotic LLC	35499901 - Assembly machines, including robotic	333519 - Rolling Mill and Other Metalworking Machinery Manufacturing
Shark	35599925 - Robots, molding and forming plastics	333249 - Other Industrial Machinery Manufacturing
Ares Robotics LLC	35630202 - Robots for industrial spraying, painting, etc.	333912 - Air and Gas Compressor Manufacturing
Boston Dynamics	35699914 - Robots, assembly line: industrial and commercial	333999 - All Other Miscellaneous General Purpose Machinery Manufacturing
Dive Technologies	37319906 - Submersible marine robots, manned or unmanned	336611 - Ship Building and Repairing
Vecna Robotics	87420101 - Automation and robotics consultant	541611 - Administrative Management and General Management Consulting Services

Using the D&B Hoovers companies database, we identified the 169 unique firms with more than 20 employees that are classified by one of the 9 SIC8 codes. These firms are classified into one of six NAICS codes. These three codes are listed in Table 15. Occupation data available from the BLS is organized in a truncated version of NAICS, with most industries organized at the three- or four-digit level. As such, Table 15 also lists the three BLS equivalent codes that capture this same scope for the robotics industry.

Table 15. Most common NAICS codes for firms identified as in the robotics industry. These codes capture 85% of firms identified.

NAICS Code	NAICS Description	BLS Equivalent Code
334516	Analytical Laboratory Instrument Manufacturing	334500
333999	All Other Miscellaneous General Purpose Machinery Manufacturing	3330A1
333519	Rolling Mill and Other Metalworking Machinery Manufacturing	333500
334513	Instruments and Related Products Manufacturing for Measuring, Displaying, and Controlling Industrial Process Variables	334500
333922	Conveyor and Conveying Equipment Manufacturing	3330A1
333249	Other Industrial Machinery Manufacturing	3330A1

In summary, we discern the robotics industry as firms classified as one of the 9 codes within the SIC8 system which maps to the three BLS equivalent industrial classification codes 334500, 3330A1, and 333500. Effectively, we are defining the industry of interest as a hybrid of these industries. This hybrid industry description, will be used to identify relevant occupations.

Posit Relevant Occupations and Skills

Identify Relevant Occupations

To leverage the extensive surveying knowledge embedded within the O*NET database (U.S. Department of Labor 2020), we use the BLS equivalent NAICS codes to identify a relevant set of occupations for our industry of interest.

Specifically, occupation codes were identified using a combination of the 2018 National Employment Matrix (NEM) (U.S. Bureau of Labor Statistics 2018) and the O*NET database. Using this dataset, we identified occupations that met the following criteria:

- Associated with the industry of interest (as defined by the codes identified previously)
- Technical in nature (see next paragraph)
- Primarily held by middle-skilled workers (see two paragraphs down)
- Represented more than 0.1% of the workforce across the defined industry

The definition of technical work is inherently subjective. For our purposes here, we limit our search to jobs associated with the Standard Occupational Classification (SOC) codes listed in Table 16. That includes occupations involved in mathematics, architecture, engineering, life, physical, and social sciences, installation, maintenance, repair, and

production. Computer related positions were excluded because in early test interviews we learned that skills for those positions would not be influenced by the specific industry.

Table 16. Standard Occupational Classification codes considered in this study.

Standard Occupation Classification Code (2-digit level)	Class Name
15-0000	Computer and mathematical occupations (excluding 15-1: Computer occupations)
17-0000	Architecture and engineering occupations
19-0000	Life, physical, and social science occupations
49-0000	Installation, maintenance, and repair occupations
51-0000	Production occupations

Middle-skilled workers are often defined as those with an education level that is greater than a high school diploma and less than a Bachelor's degree (Fuller and Raman 2017). Occupations are always held by workers with a range of education. For this research, we define middle-skilled occupations to be those for which both greater than 30% of the workforce is middle skilled and less than 50% of the workforce is either lower-skilled or upper-skilled.

Based on these definitions, we identified 17 relevant middle-skilled positions associated with the robotics industry. To facilitate survey data collection, these were grouped into eight representative positions, as shown in bold in

Table 17. This set includes six types of engineering technicians – electrical / electronic, industrial, mechatronics, mechanical, and chemical– as well as technical maintenance personnel (e.g., mechanics, electricians), computer-numerical-controlled machine operators, and machinists.

Table 17. Focal occupations that were evaluated in this study. Bold titles represent representative occupations that were served as proxy for the subsequent specific occupations.

Occupation	Standard Occupation Classification Code
Middle-skilled	
Electrical and electronics engineering technicians(representing)	
Electrical and electronics engineering technicians	17-3023
Electrical and electronics drafters	17-3012
Electro-mechanical technicians	17-3024
Industrial engineering technicians(representing)	
Industrial engineering technicians	17-3026
Aerospace engineering and operations technicians	17-3021
Mechanical engineering technicians(representing)	
Mechanical engineering technicians	17-3027
Mechanical drafters	17-3013
Chemical technicians	19-4031
Maintenance and Support Technicians (representing)	
Industrial machinery mechanics	49-9041
Maintenance workers, machinery	49-9043
HVAC mechanics and installers	49-9021
Mobile heavy equipment mechanics, except engines	49-3042
Electrical & electronics repairers, commercial & ind. equipment	49-2094
Computer-controlled machine tool operators(representing)	
Computer-controlled machine tool operators	51-4011
Computer numerically controlled machine tool programmers	51-4012
Other Technical Production Worker (representing)	
Machinists	51-4041
Tool and die makers	51-4111
Installation and deployment technician	See note in results

Identify Relevant Skills

For each identified occupation, an associated set of competencies (skills) and tools was developed from two sources of job characterization information: the U.S. Department of Labor O*Net database (U.S. Department of Labor 2020) and a real-time labor market intelligence analytics database, Burning Glass Labor Insight™ (Burning Glass Technologies 2021). The O*Net database uses a hierarchical taxonomic approach to organize tasks and skills. (Peterson et al. 2001). The database was originally developed

through survey methods to create a relational database of occupation attributes for the U.S. economy (Peterson et al. 2001) and helps create a common language for job descriptors. For each occupation, the database includes tasks in the job, tools employed in the job, and technologies employed on the job. An example of tools and competencies collected is shown in Figure 18 for an Electrical Engineering Technician.

Using all of this information, the research team selected six to ten technical skills for each occupation based on the O*NET task descriptions to characterize their importance and any existing skills gap for these skills within the robotics industry. The specific skills explored are listed in the results plots and tables in the results section of the report.

Electrical Engineering Technician

Competencies:

- Diagnose, test, or analyze the performance of electrical components, assemblies, or systems.
- Calculate design specifications or cost, material, and resource estimates, and prepare project schedules and budgets.
- Compile and maintain records documenting engineering schematics, installed equipment, installation or operational problems, resources used, repairs, or corrective action performed.
- Set up and operate standard or specialized testing equipment.
- Review, develop, and prepare maintenance standards.
- Install or maintain electrical control systems, industrial automation systems, or electrical equipment, including control circuits, variable speed drives, or programmable logic controllers.
- Design or modify engineering schematics for electrical transmission and distribution systems using computer-aided design (CAD) software.
- Supervise the construction or testing of electrical prototypes, according to general instructions and established standards.

Tools:

- Microcontrollers (e.g., Programmable logic controllers PLC)
- Electronic measuring probes (e.g., Probe stations)
- Multimeters
- Voltage or current meters (e.g., Analog current meters, Digital voltmeters DVM, Standing wave ratio SWR meters)
- Network analyzers
- Frequency analyzers (e.g., Spectrum analyzers)
- Frequency counters or timer or dividers (e.g., Microwave frequency counters)
- Reflectometers (e.g., Optical time domain reflectometers OTDR)
- Signal generators
- Development environment software
- Program testing software
- Analytical or scientific software

Figure 18 Competencies and tools associated with the job title electrical engineering technician.

Emerging Technical Skills

While the O*NET database provides valuable insight into the current technical skills needed for these occupations, the research team also wanted to get a sense of what skills are emerging as important within the robotics industry.

To accomplish this, we made use of two methods to identify potentially relevant emerging skills. The first method relied on discussions of the changing nature of work within the academic literature. Specifically, based on information within MIT Production in the Innovation Economy (PIE) survey (Weaver and Osterman 2017), the essential skills framework used by the Canadian government (Government of Canada 2015), and the Future of Work report (Autor, Mindell, and Reynolds 2020). Based on the authors' synthesis of these reports, we identified the following skills as potentially relevant and emerging for technical middle-skilled workers in manufacturing:

- Programming and troubleshooting automated process equipment (CNC, programmable production equipment, etc.)
- Conducting and assessing the results of statistical process control analyses or design of experiments
- Optimizing production flow based on the use of qualitative observations and quantitative analytics
- Using lean manufacturing principles (value stream mapping, minimize waste)
- Decreasing inventory and stockouts by understanding your own operations and your suppliers
- Working with digital collaboration tools (Computerized maintenance management software, connected worker platforms, workflow management, etc.)

The second method was to make use of a real-time labor market intelligence analytics database to identify emerging skills for each occupation. Burning Glass Labor Insight™ (BGLI) collects job posting data from job boards, firm websites, and job ad websites that represent more than 40,000 online resources and 3.4 million jobs (Burning Glass Technologies 2021). Duplicate postings are removed and natural language processing methods extract the in-demand occupations, skills, and credentials. Two approaches were used to identify relevant skills list from the BGLI database. It is important to note that while we did not specifically include tools and technologies in our interviews due to limited time; however, knowledge of in-demand tools and technologies can help inform trends in the robotics industry.

In the first approach, referred to as a keyword-based query, we attempted to identify relevant skills by querying middle-skilled posting associated with manufacturing and with

the keywords “robotic(s)” or “automation”. Specifically, we applied the filters shown in Table 18 Table 2 which yielded 130,456 job postings. Finally, we also applied a filter where the job title must include “technician” to narrow the search results and reduce the noise in the data. This approach helped to identify technician specific skills and isolate skills that are average within the industry (e.g. Microsoft Office Suite) resulting in 37,557 postings.

Table 18. Filter criteria applied for relevant education levels and keywords in the Labor Insight™ database.

Criteria	Filter Applied
Time Period	07/01/2016-06/31/2021
Education	High school or vocational training or Associate's degree
Industry	Manufacturing
Keywords	Robotic, robotics, automation
Location	Nationwide
Title includes	Technician

In a second approach, referred to as an employer-based query, we searched for relevant and current skills by querying postings specifically associated with the three middle-skilled technician positions identified within BGLI – robotics technician, industrial/mechanical engineering technician, or general engineering technician – and with firms specifically known to be in the robotics industry. The filtering on employer and types of occupations as shown in Table 19, resulting in 5,326 job postings. To once again narrow the search and reduce noise in the dataset, the “technician” filter was added, reducing the number of postings to 2,926.

Table 19. Filter criteria applied for relevant employers and occupations in the Labor Insight™ database.

Criteria	Filter Applied
Time Period	07/01/2016-06/31/2021
Occupation(s)	Robotics technician or general engineering technician or industrial/mechanical engineering technician
Employer	180 robotics firms
Location	Nationwide
Title includes	Technician

The top 200 skills were identified from both approaches and compared with the O*NET tasks, detailed work activities, tools (and examples), and technologies (and examples) associated with the four technician positions found in both databases: electrical

engineering technicians, mechanical engineering technicians, industrial engineering technician, and electro-mechanical and mechatronic technicians.

To identify skills not represented in the O*NET database, we performed a two-stage assessment. First, an NLP tool, UDPipe in R (Wijffels 2021), was used to lemmatize⁷ the text of both the BGLI skills and the O*NET data and, then, to identify matches between the two. Matches and partial matches of at least 25% commonality were flagged for human evaluation. Based on this, skills or tools that were present in BGLI but not in O*NET were flagged to ensure all emerging skills, tools, and technologies are identified to inform curriculum development and training.

The O*NET database is a source of comprehensive job classification information with detail and context that is needed for in person interviews. The BGLI data is uniquely able to identify emergent skills and technologies in the field, but the information can require effort to contextualize given their brevity and occasional specificity. Overall, O*NET and Burning Glass Labor Insight™ complement one another in the skills gap analysis for the robotics industry.

Delays in accessing the BGLI database and the pressing need to deliver results in a timely manner, resulted in BGLI results not being available *before* interviews began. As such, for this report, we were unable to explicitly include emerging skills flagged by the BGLI analysis within industry interviews. While there were very few such skills that were absent from the survey questions, it is still important to identify them. As such, we call these out in the results section in Figure 13 and Appendix Figure 19-Figure 21 and Table 20-Table 23 and recommend that all programs monitor the importance of these skills to their local industry.

⁷Lemmatization is a linguistics process of combining the inflected parts of a word to analyze them as a single item. It is a common natural language processing technique.

Mechatronics Technician Skills

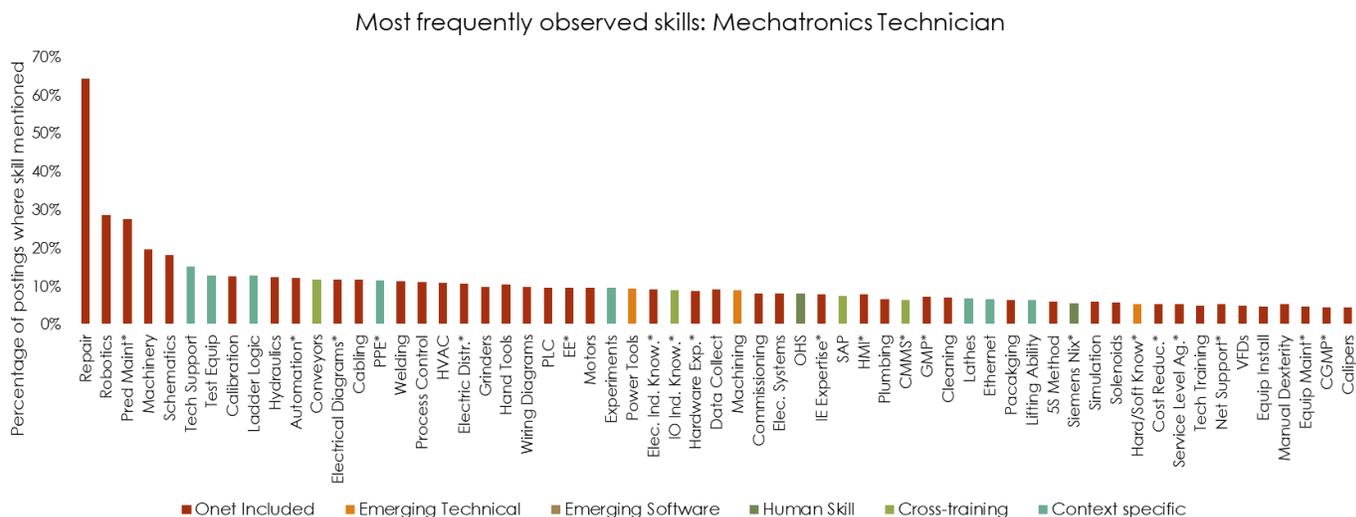


Figure 19. The most frequently observed skills for mechatronics technicians classified as ONET included, emerging technical, emerging software, human skill, cross-training, or context specific.

Table 20 Skills in at least 5% of postings for mechatronics technicians from the employer and keyword approach. The maximum percentage of postings where the skill was mentioned was reported.

Skill	Skill Category	Percent of postings skill mentioned
Repair	ONET Included	64%
Robotics	ONET Included	29%
Predictive / Preventative Maintenance	ONET Included	28%
Machinery	ONET Included	20%
Schematic Diagrams	ONET Included	18%
Welding	Context Specific	15%
HVAC	Context Specific	13%
Hand Tools	ONET Included	13%
Wiring	ONET Included	12%
Technical Support	Emerging Technical	12%
Electronics Industry Knowledge	Cross-training	12%
Test Equipment	ONET Included	12%
Calibration	ONET Included	12%
Packaging	Context Specific	12%
Programmable Logic Controller (PLC) Programming	ONET Included	11%
Hydraulics	ONET Included	11%
Automation Systems	ONET Included	11%
Power Tools	ONET Included	11%
Electrical Diagrams / Schematics	ONET Included	10%

Commissioning	ONET Included	9%
Industrial Operations Industry Knowledge	Cross-training	9%
Electrical Systems	ONET Included	9%
Occupational Health and Safety	ONET Included	8%
Machining	ONET Included	8%
Lifting Ability	Human Skill	8%
Human Machine Interface (HMI)	ONET Included	8%
Industrial Engineering Industry Expertise	Cross-training	8%
Personal Protective Equipment (PPE)	ONET Included	10%
Good Manufacturing Practices (GMP)	ONET Included	7%
Electrical Engineering	Cross-training	7%
Cleaning	ONET Included	6%
Plumbing	Context Specific	10%
Lathes	ONET Included	6%
5S Methodology	Emerging Technical	5%
Grinders	ONET Included	5%
Variable Frequency Drives (VFDs)	ONET Included	5%
Process Control	ONET Included	10%
Equipment Installation	ONET Included	5%
Servo Drives / Motors	ONET Included	5%
Equipment Maintenance	ONET Included	5%
Current Good Manufacturing Practices (CGMP)	ONET Included	5%
Technical Training	ONET Included	5%
Calipers	ONET Included	5%
Ladder Logic	ONET Included	5%
Ethernet	ONET Included	5%
Siemens Nixdorf Hardware	Context Specific	13%
Conveyor Systems	ONET Included	10%
Cabling	ONET Included	10%
Hardware Experience	ONET Included	10%
Simulation	Emerging Technical	10%
Data Collection	ONET Included	9%
Root Cause Analysis	Emerging Technical	9%
SAP	ONET Included	8%
Electrical Distribution Systems	ONET Included	7%
Computerized Maintenance Management System (CMMS)	ONET Included	7%
Solenoids	Context Specific	7%
Soldering	Context Specific	7%

Experiments	ONET Included	6%
Network Support	Context Specific	6%
Computer Hardware/Software Knowledge	ONET Included	6%
Manual Dexterity	ONET Included	6%
Operational Cost Reductions	ONET Included	5%
Service Level Agreement	ONET Included	5%

Mechanical Engineering Technician

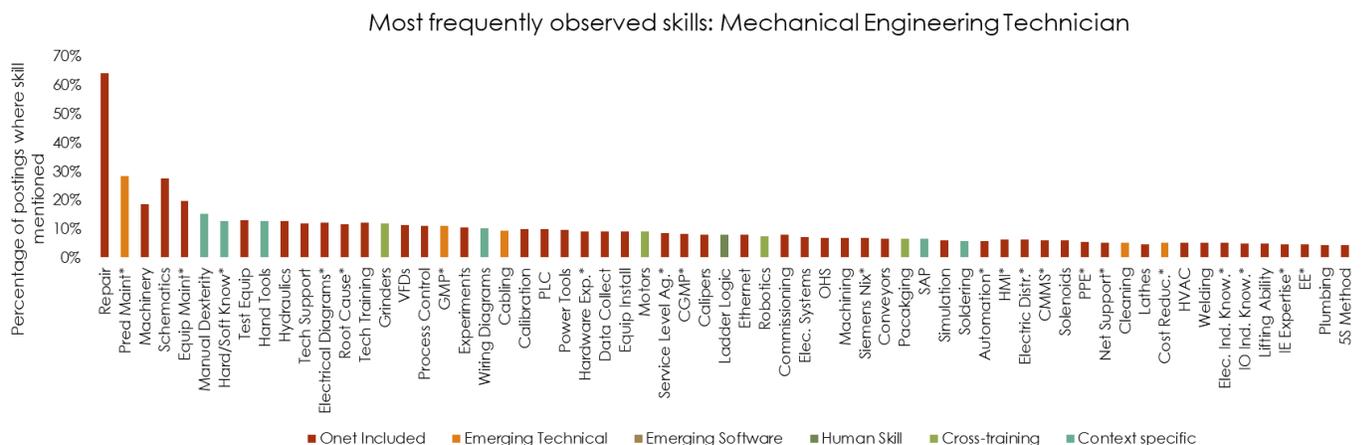


Figure 20 The most frequently observed skills for mechanical engineering technicians classified as ONET included, emerging technical, emerging software, human skill, cross-training, or context specific.

Table 21 Skills in at least 5% of postings for mechanical engineering technicians from the employer and keyword approach. The maximum percentage of postings where the skill was mentioned was reported.

Skill	Skill Category	Percentage of postings skills mentioned
Repair	ONET Included	64%
Robotics	Emerging Technical	29%
Schematic Diagrams	ONET Included	19%
Predictive / Preventative Maintenance	ONET Included	28%
Test Equipment	ONET Included	13%
Siemens Nixdorf Hardware	Context Specific	13%
Conveyor Systems	Context Specific	10%
Packaging	Context Specific	12%
Cabling	ONET Included	10%
Electrical Diagrams / Schematics	ONET Included	10%

Hand Tools	ONET Included	13%
Hardware Experience	ONET Included	10%
Wiring	ONET Included	12%
Simulation	Emerging Technical	10%
Data Collection	ONET Included	9%
Root Cause Analysis	ONET Included	9%
SAP	ONET Included	8%
Calibration	ONET Included	12%
Electrical Distribution Systems	ONET Included	7%
Computerized Maintenance Management System (CMMS)	ONET Included	7%
Solenoids	ONET Included	7%
Soldering	Context Specific	7%
Experiments	ONET Included	6%
Network Support	ONET Included	6%
Computer Hardware/Software Knowledge	ONET Included	6%
Equipment Maintenance	ONET Included	6%
Manual Dexterity	ONET Included	6%
Automation Systems	Emerging Technical	11%
Power Tools	ONET Included	11%
Technical Training	ONET Included	5%
Operational Cost Reductions	Emerging Technical	5%
HVAC	Context Specific	13%
Machinery	ONET Included	20%
Service Level Agreement	ONET Included	5%
Welding	Context Specific	15%
Technical Support	ONET Included	12%
Electronics Industry Knowledge	Cross-Training	12%
Programmable Logic Controller (PLC) Programming	ONET Included	11%
Hydraulics	ONET Included	11%
Commissioning	ONET Included	9%
Industrial Operations Industry Knowledge	Cross-Training	9%
Electrical Systems	ONET Included	9%
Occupational Health and Safety	ONET Included	8%
Machining	ONET Included	8%
Lifting Ability	Human Skill	8%
Human Machine Interface (HMI)	ONET Included	8%

Industrial Engineering Industry Expertise	Cross-Training	8%
Personal Protective Equipment (PPE)	ONET Included	7%
Good Manufacturing Practices (GMP)	ONET Included	7%
Electrical Engineering	Cross-Training	7%
Cleaning	ONET Included	6%
Plumbing	Context Specific	6%
Lathes	ONET Included	6%
5S Methodology	Emerging Technical	5%
Grinders	ONET Included	5%
Variable Frequency Drives (VFDs)	ONET Included	5%
Process Control	ONET Included	5%
Equipment Installation	ONET Included	5%
Servo Drives / Motors	ONET Included	5%
Current Good Manufacturing Practices (CGMP)	ONET Included	5%
Calipers	ONET Included	5%
Ladder Logic	ONET Included	5%
Ethernet	ONET Included	5%

Electrical Engineering Technician

Most frequently observed skills: Electrical Engineering Technician

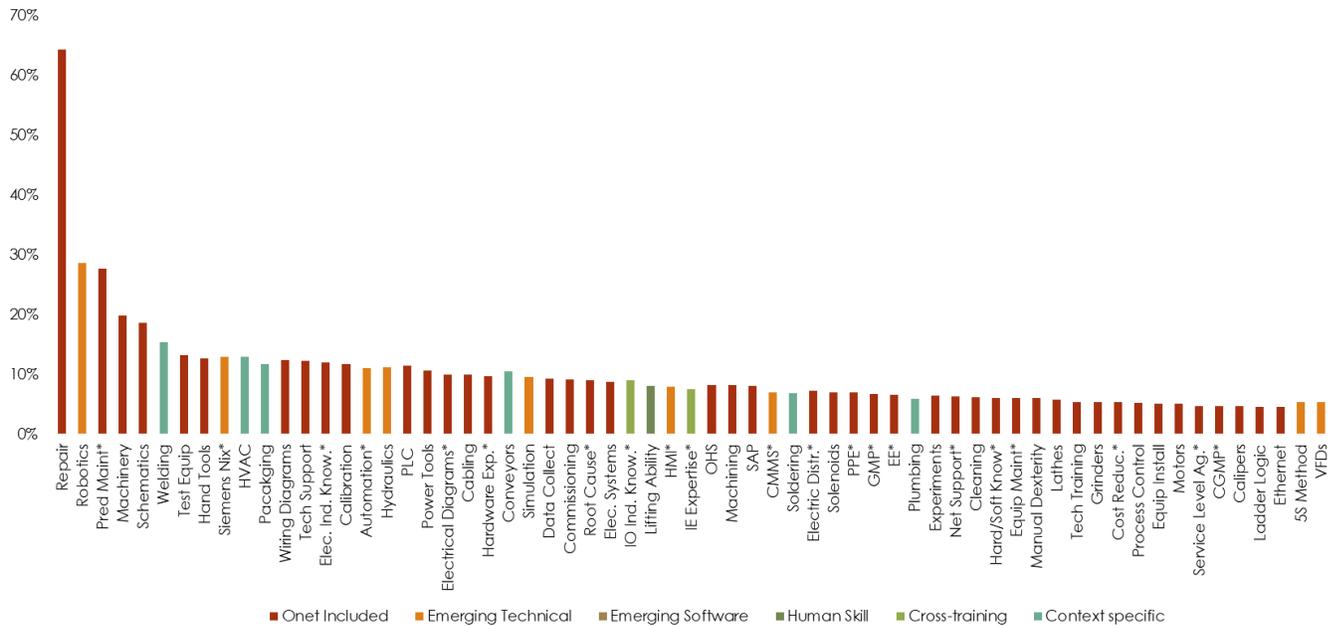


Figure 21 The most frequently observed skills for electrical engineering technicians classified as ONET included, emerging technical, emerging software, human skill, cross-training, or context specific.

Table 22 Skills in at least 5% of postings for electrical engineering technicians from the employer and keyword approach. The maximum percentage of postings where the skill was mentioned was reported.

Skill	Skill Category	Percentage of postings skills mentioned
Repair	ONET Included	64%
Robotics	Emerging Technical	29%
Schematic Diagrams	ONET Included	19%
Predictive / Preventative Maintenance	ONET Included	28%
Test Equipment	ONET Included	13%
Siemens Nixdorf Hardware	Emerging Technical	13%
Conveyor Systems	Context Specific	10%
Packaging	Context Specific	12%
Cabling	ONET Included	10%
Electrical Diagrams / Schematics	ONET Included	10%
Hand Tools	ONET Included	13%
Hardware Experience	ONET Included	10%
Wiring	ONET Included	12%
Simulation	Emerging Technical	10%
Data Collection	ONET Included	9%
Root Cause Analysis	ONET Included	9%
SAP	ONET Included	8%
Calibration	ONET Included	12%
Electrical Distribution Systems	ONET Included	7%
Computerized Maintenance Management System (CMMS)	Emerging Technical	7%
Solenoids	ONET Included	7%
Soldering	Context Specific	7%
Experiments	ONET Included	6%
Network Support	ONET Included	6%
Computer Hardware/Software Knowledge	ONET Included	6%
Equipment Maintenance	ONET Included	6%
Manual Dexterity	ONET Included	6%
Automation Systems	Emerging Technical	11%
Power Tools	ONET Included	11%
Technical Training	ONET Included	5%
Operational Cost Reductions	ONET Included	5%
HVAC	Context Specific	13%
Machinery	ONET Included	20%
Service Level Agreement	ONET Included	5%
Welding	Context Specific	15%
Technical Support	ONET Included	12%
Electronics Industry Knowledge	ONET Included	12%

Programmable Logic Controller (PLC) Programming	ONET Included	11%
Hydraulics	Emerging Technical	11%
Commissioning	ONET Included	9%
Industrial Operations Industry Knowledge	Cross-training	9%
Electrical Systems	ONET Included	9%
Occupational Health and Safety	ONET Included	8%
Machining	ONET Included	8%
Lifting Ability	Human Skill	8%
Human Machine Interface (HMI)	Emerging Technical	8%
Industrial Engineering Industry Expertise	Cross-training	8%
Personal Protective Equipment (PPE)	ONET Included	7%
Good Manufacturing Practices (GMP)	ONET Included	7%
Electrical Engineering	ONET Included	7%
Cleaning	ONET Included	6%
Plumbing	Context Specific	6%
Lathes	ONET Included	6%
5S Methodology	Emerging Technical	5%
Grinders	ONET Included	5%
Variable Frequency Drives (VFDs)	Emerging Technical	5%
Process Control	ONET Included	5%
Equipment Installation	ONET Included	5%
Servo Drives / Motors	ONET Included	5%
Current Good Manufacturing Practices (CGMP)	ONET Included	5%
Electrical Engineering	ONET Included	7%
Cleaning	ONET Included	6%
Plumbing	Context Specific	6%
Lathes	ONET Included	6%
5S Methodology	Emerging Technical	5%
Grinders	ONET Included	5%
Variable Frequency Drives (VFDs)	Emerging Technical	5%
Process Control	ONET Included	5%
Equipment Installation	ONET Included	5%
Servo Drives / Motors	ONET Included	5%
Current Good Manufacturing Practices (CGMP)	ONET Included	5%
Calipers	ONET Included	5%
Ladder Logic	ONET Included	5%
Ethernet	ONET Included	5%

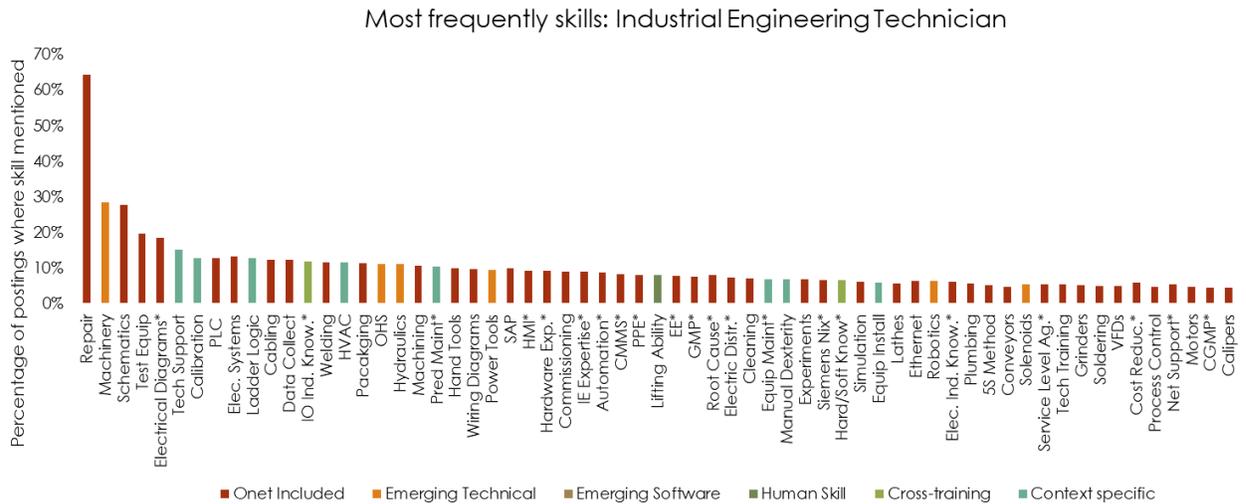


Figure 22 The most frequently observed skills for industrial engineering technicians classified as ONET included, emerging technical, emerging software, human skill, cross-training, or context specific.

Table 23 Skills in at least 5% of postings for industrial engineering technicians from the employer and keyword approach. The maximum percentage of postings where the skill was mentioned was reported.

Skill	Skill Category	Percentage of postings skills mentioned
Repair	ONET Included	64%
Robotics	Emerging Technical	29%
Predictive / Preventative Maintenance	ONET Included	28%
Machinery	ONET Included	20%
Schematic Diagrams	ONET Included	19%
Welding	Context Specific	15%
HVAC	Context Specific	13%
Hand Tools	ONET Included	13%
Wiring	ONET Included	12%
Technical Support	ONET Included	12%
Electronics Industry Knowledge	Cross-Training	12%
Test Equipment	ONET Included	13%
Calibration	ONET Included	12%
Packaging	Context Specific	12%
Programmable Logic Controller (PLC) Programming	ONET Included	11%
Hydraulics	Emerging Technical	11%
Automation Systems	Emerging Technical	11%
Power Tools	ONET Included	11%
Electrical Diagrams / Schematics	ONET Included	10%

Commissioning	ONET Included	9%
Industrial Operations Industry Knowledge	ONET Included	9%
Electrical Systems	ONET Included	9%
Occupational Health and Safety	ONET Included	8%
Machining	ONET Included	8%
Lifting Ability	Human Skill	8%
Human Machine Interface (HMI)	ONET Included	8%
Industrial Engineering Industry Expertise	ONET Included	8%
Personal Protective Equipment (PPE)	ONET Included	7%
Good Manufacturing Practices (GMP)	ONET Included	7%
Electrical Engineering	Cross-Training	7%
Cleaning	ONET Included	6%
Plumbing	Context Specific	6%
Lathes	ONET Included	6%
5S Methodology	Emerging Technical	5%
Grinders	ONET Included	5%
Variable Frequency Drives (VFDs)	ONET Included	5%
Process Control	ONET Included	5%
Equipment Installation	ONET Included	5%
Servo Drives / Motors	ONET Included	5%
Equipment Maintenance	ONET Included	6%
Current Good Manufacturing Practices (CGMP)	ONET Included	5%
Technical Training	ONET Included	5%
Calipers	ONET Included	5%
Ladder Logic	ONET Included	5%
Ethernet	ONET Included	5%
Siemens Nixdorf Hardware	Context Specific	13%
Conveyor Systems	Context Specific	10%
Cabling	ONET Included	10%
Hardware Experience	ONET Included	10%
Simulation	Emerging Technical	10%
Data Collection	ONET Included	9%
Root Cause Analysis	ONET Included	9%
SAP	ONET Included	8%
Electrical Distribution Systems	ONET Included	7%
Computerized Maintenance Management System (CMMS)	ONET Included	7%
Solenoids	Context Specific	7%
Soldering	Context Specific	7%
Experiments	ONET Included	6%
Network Support	Emerging Technical	6%

Computer Hardware/Software Knowledge	ONET Included	6%
Manual Dexterity	ONET Included	6%
Operational Cost Reductions	ONET Included	5%
Service Level Agreement	ONET Included	5%

Human Skills: What about “Soft” skills?

The focus of this study was to assess the training gaps associated with specific applied skills for technical workers. This focus in no way implies that the research team believes that such technical skills are more important than other non-technical skills (also known as “soft” or human skills). Research was focused on technical skills for two reasons. First, our primary goal was to develop insights to shape training programs aimed to support the robotics industry. Such programs themselves focus on technical skills and, therefore, require feedback on the same. Secondly, the interview applied in this research was of a scale that taxed most respondents. As such, tradeoffs had to be made to limit its scope and content. As a result, this study explores only a limited set of human skills including a novel analysis of critical thinking.

Although they were not the focus of this study, it is important for training programs to recognize that human skills complement technical skills, enhance employability, and improve productivity (Schulz 2008; Rao 2014). Although both industry and academia are reaching consensus that employees need human skills in addition to the technical skills taught in most STEM training programs (Kumar and Hsiao 2007), there is no consensus on which human skills are most important or even how to frame and organize human skills.

A recent study by researchers at MIT’s Jameel World Education Lab attempts to bridge that gap by synthesizing more than 40 skills frameworks into the Human Skills Matrix (HSM). Their analysis found that communication and self-management skills were the most commonly identified important human skills. These were followed by creativity, problem solving, critical thinking, and teamwork. The HSM synthesizes this information into 24 non-technical skills that employees need to thrive (Stump, Westerman, and Hall 2020). These skills are grouped into four categories including Thinking, Interacting, Managing ourselves, and Leading. This framework was used to guide the selection of human skills studied here.

Specifically, we asked operations managers about the importance of these six human skills (as well as a detailed question about critical thinking) for middle-skilled manufacturing occupations:

- Effectively managing people and projects (Leading)
- Managing unfamiliar problems and situations (Thinking)
- Independently organizing time or prioritizing tasks (Managing ourselves)

- Communicating and collaborating with engineering and management staff (Interacting)
- Taking initiative to learn new skills or technologies (Managing ourselves)
- Knowing the science and engineering underlying the product (Thinking)

Critical thinking is widely cited as a skill that leads to success. Nevertheless, there are no established methods to characterize it. Here we define critical thinking as “the ability to analyze evidence and facts to form a judgment” (Gambrill 2005). To better characterize the role of critical thinking for technical middle-skilled occupations, we decompose the judgment process into the following sub-tasks:

1. Perceiving the issue – What should I measure or observe to know that a problem exists?
2. Hypothesizing about problem cause – What might be causing the problem?
3. Developing a framework for hypothesis testing – How can I confirm my hypothesis?
4. Inferring whether tests confirm the hypothesis - Does the test suggest that my hypothesis was right?
5. Communicating the outcome – How (and to whom) do I report on what has happened?

Respondents were asked to identify what aspect of critical thinking is important of technicians working at their facility.

Identifying Important, Common Skills

While it is valuable to understand the skills trends within individual occupations, in many cases, training programs or courses will need to be more broadly applicable, serving the needs of multiple types of learners. To that end, the research team has attempted to identify those skills that are both important and shared (common) among multiple occupations.

This was accomplished by making use of the hierarchical nature of the O*NET dataset from which occupation-specific skills were identified. To create the survey administered for this project, the research team identified occupation-specific skills from the list of Tasks within the O*NET dataset. In that context, Tasks are the most specific representation of occupation requirements. Tasks are related to more generalized classifications of skills as represented in Figure 23. Specifically, Tasks can be associated with many Detailed Work Activities which are each associated with only one Intermediate Work Activity which are themselves associated with only one General Work Activity. (To maintain a more consistent terminology in this report, we will refer to these classifications as Detailed Tasks/Skills (DTS), Intermediate Tasks/Skill (ITS), and General Tasks/Skills (GTS), respectively.)

Because of this hierarchical relationship, it was possible to compute an average skill importance at any level of aggregation. To do this, a weighting was assigned to each level of response for each specific skill (Importance will Grow Significantly = 5, Grow = 3,

Hold = 1, Not important = 0). Then weighted averages of these importance levels were computed for each specific task or skill and the corresponding DTS, ITS, and GTS. For this set of occupations, the DTS level of aggregation did not provide useful insights. As such, it is not discussed further in the results section.

These weighted importance scores were then used to identify the most important GTS and ITS across all of the occupations considered in this survey. From these important skills we identify those that are shared by at least three occupations and refer to this set as important, common (as in shared) skills.

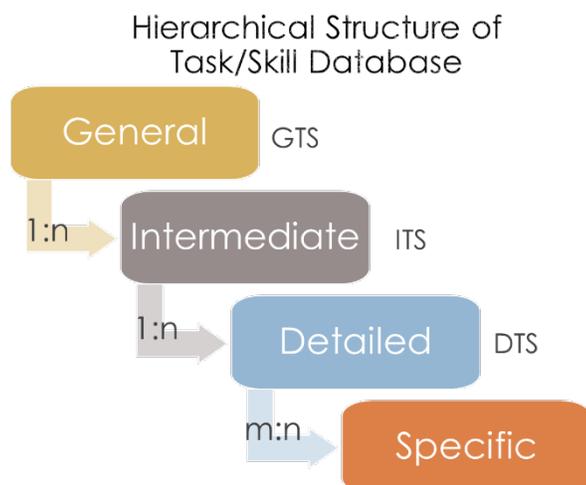


Figure 23. Hierarchical structure of the task/skill database used in this study. Survey respondents were asked about occupation specific (orange level) tasks or skill. 1:n indicates a one (parent) to many (child) relationship. m:n indicates a many to many relationship. The hierarchies are defined within the O*NET database.

Semi-Structured Interview

Interview design

The interview is structured into four main sections:

1. firm characterization,
2. hiring and training challenges
3. workforce scaling, and
4. emerging and human skill needs, including critical thinking

In the first section of the interview, respondents were asked to identify the primary role that their firm plays in the robotics supply chain. Additionally, respondents were asked to estimate the firm's annual revenues and overall employment levels.

In the second section, respondents were asked to identify which of the focal occupations were relevant for their firm. Then for each relevant occupation they were asked whether

- Demand for that position would (Hold, Grow Somewhat, or Grow Significantly)?
- Filling an open position was (Easy, Average, or Hard)?
- In house training for new hires tends to be (Basic, Moderate, or Extensive training)?

Next, respondents were randomly assigned three relevant occupations. For each of these, they were asked to characterize the expected skill level for each position for their current technicians, the skill level of new hires for these positions, and rank the importance of the skills in 5 years compared to today. The categories for skill level included the following:

- Not applicable
- Aware of
- Familiar with
- Competent at
- Proficient with
- Mastery of

The expected importance ranks from much less important than now to much more important than now.

For each of these positions, respondents were asked to evaluate the importance of emerging skills when evaluating a new hire in five years. The importance categories included the following:

- Extremely important
- Very important
- Moderately important
- Slightly important
- Not at all important

Finally, the closing questions of the interview included in-depth questions about critical thinking and troubleshooting for technicians relevant to the respondent's firm. The respondents were asked to identify which of the judgments in the critical thinking process were most common for each technician ranging from:

- Issue perception
- Cause hypothesizing
- Hypothesis testing
- Test result inference
- Reporting and recommending

It was assumed that if a respondent chose "reporting and recommending" then they felt that the technician was capable of performing all of the previous steps as well.

To understand the importance of troubleshooting for hiring, respondents were asked to explain the relevance of this ability at their firm and how they test and train troubleshooting abilities.

Semi-Structured Interview Process

The interview responses were captured in the Qualtrics online platform (Qualtrics XM 2021) and interviews were conducted with robotics firms located in the New England area. Thirty-one responses where the respondent completed the entirety of the interview template were received and incorporated into the following results.

BLS Comparison to ARM Industry 4.0 Competency Building Blocks

Table 24 A comparison between the ARM building blocks and the BLS and Emerging Skill Competencies.

ARM Competency	BLS Competency/Emerging Skill Equivalent
Mechanical systems	Test performance of electromechanical assemblies, using test instruments such as oscilloscopes, electronic voltmeters, or bridges.
Safety	Determine whether selected electromechanical components comply with environmental standards and regulations.
Electronics & controls	Install electrical or electronic parts and hardware in housings or assemblies, using soldering equipment and hand tools.
Fluid power	Repair, rework, or calibrate hydraulic or pneumatic assemblies or systems to meet operational specifications
Maintenace & troubleshooting	Programming and troubleshooting automated process equipment (CNC, programmable production equipment, etc.)
Robot programming	Develop, test, or program automated production equipment or other robotic systems
Electrical systems	Install electrical or electronic parts and hardware in housings or assemblies, using soldering equipment and hand tools.
PLC	Install or program computer hardware or machine or instrumentation software in microprocessor-based systems

Respondent Demographics

Survey respondents came from a broad array of firms. As shown in Figure 24a, a majority of the respondents came from Massachusetts, with a few firms from other New England states. Firms ranged in size from as few as seven employees to as many as 1.2 million. The median firm size was 240 employees. Annual revenue ranged from \$0 to \$380B with a median of \$5M per year (Figure 24b).

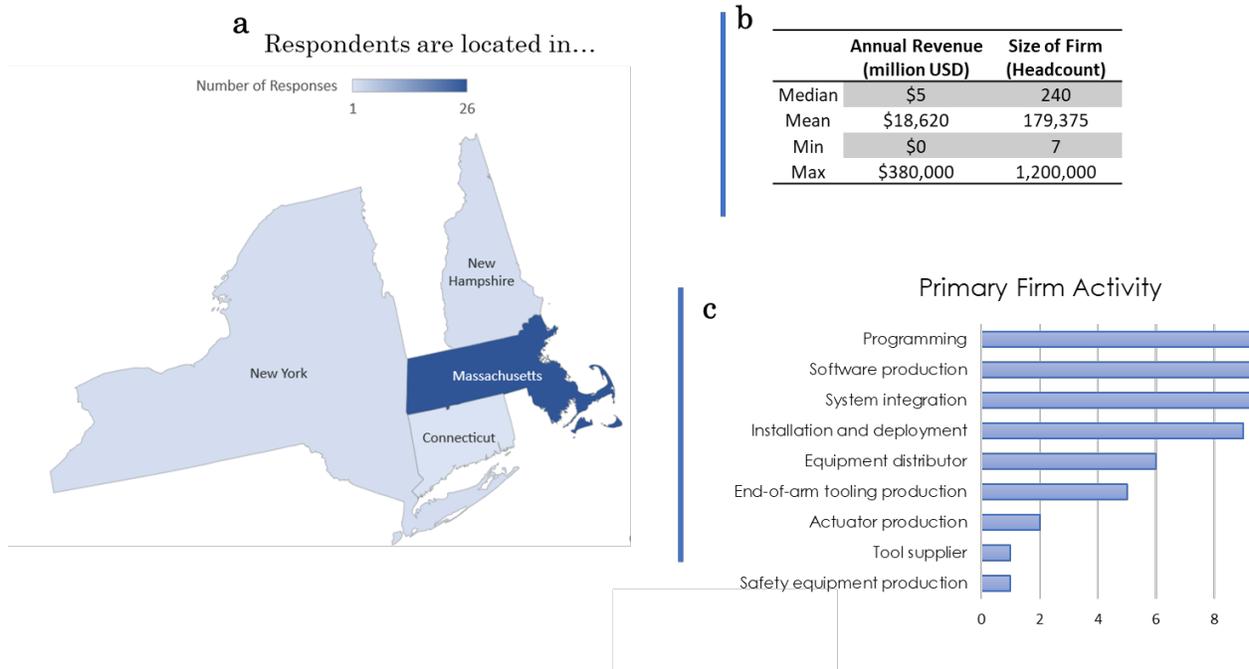


Figure 24. Distribution of respondent location, size, revenue, and primary supply chain activity.

Firms were asked to identify their role in the supply chain. There was a range of primary activities for each firm (see Figure 24c) with a majority focused on programming, software production, and system integration.

Common Important Skills

The following pages contain the details of survey responses for each specific skill organized by Intermediate Task/Skill (ITS) and by General Task/Skill (GTS). In the subsequent tables, occupation titles are abbreviated as listed in Table 25.

Table 25. Focal occupations that were evaluated in this study and abbreviated title used in GTS / ITS tables

Occupation	Abbreviation
Industrial engineering technicians	Ind Eng T
Electrical and electronics engineering technicians	ElecEng T
Mechanical engineering technicians	MechEng T
Chemical technicians	Chemical T
Computer-controlled machine tool operators	CNC Oper
Mechanical and mechatronics engineering technician	MechaTron T

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Photonic T	Ind Eng T	ElecEng T	Chemical T	MechEng T	MechaTron T	CNC Oper	Machinists
Provide Consultation and Advice to Others	3.0	Advise others on the design or use of technologies.	3.1	Provide technical assistance in resolving electrical engineering problems encountered before, during, or after construction.	3.1			X					
		Advise others on business or operational matters.	2.8	Recommend modifications to existing quality or production standards to achieve optimum quality	3.2		X						
				Review new product plans and make recommendations for material selection, based on design objectives such as strength, weight, heat resistance, electrical conductivity, and cost.	-nr-								
Repairing and Maintaining Equipment	2.9	Repair tools or equipment.	3.2	Maintain machines and remove and replace broken or worn machine tools, using hand tools.	3.2							X	
		Maintain electronic, computer, or other technical equipment.	3.1	Build, calibrate, maintain, troubleshoot, or repair electrical instruments or testing equipment.	3.1			X					
		Maintain tools or equipment.	2.8	Repair, rework, or calibrate hydraulic or pneumatic assemblies or systems to meet operational specifications	2.5						X		

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Photonic T	Ind Eng T	ElecEng T	Chemical T	MechEng T	MechaTron T	CNC Oper	Machinists
Prepare specimens, tools, or equipment	2.9	Prepare specimens or materials for testing.	3.7	Prepare chemical solutions for products or processes, following standardized formulas, or create experimental formulas.	-nr-				X				
		Set up equipment.	3.5	Mount, install, align, and secure tools, attachments, fixtures, and workpieces on machines, using hand tools and precision measuring instruments.	3.6							X	
				Set up and conduct chemical experiments, tests, and analyses, using techniques such as chromatography, spectroscopy, physical or chemical separation techniques, or microscopy.	-nr-				X				
		Install commercial or production equipment.	3.3	Install electrical or electronic parts and hardware in housings or assemblies, using soldering equipment and hand tools.	3.3						X		
		Assemble equipment or components.	3.3	Align, fit, or assemble component parts, using hand or power tools, fixtures, templates, or microscopes.	3.4						X		
				Build, calibrate, maintain, troubleshoot, or repair electrical instruments or testing equipment.	3.1			X					
		Disassemble equipment.	3.2	Maintain machines and remove and replace broken or worn machine tools, using hand tools.	3.2							X	
		Adjust equipment to ensure adequate performance.	2.7	Repair, rework, or calibrate hydraulic or pneumatic assemblies or systems to meet operational specifications	2.5						X		
		Fabricate devices or components.	1.9	Fabricate and assemble new or modified mechanical components for products such as industrial machinery or equipment, and measuring instruments.	2.6					X			
				Operate drill press, grinders, engine lathe, or other machines to modify or to fabricate components.	2.1					X			
				Operate metalworking machines to fabricate housings, jigs, fittings, or fixtures.	0.9						X		

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Photonic T	Ind Eng T	ElecEng T	Chemical T	MechEng T	MechaTron T	CNC Oper	Machinists	
Interacting With Computers	2.9	Program computer systems or production equipment.	2.9	Input machine control programs	3.2							X		
				Set up and operate computer-controlled machines or robots to perform one or more machine functions on metal or plastic workpieces.	3.0							X		
				Modify cutting programs to account for problems encountered during operation	2.6								X	
				Develop, test, or program automated production equipment or other robotic systems.	2.5							X		
Monitor Processes, Materials, or Surroundings	2.8	Monitor operations to ensure adequate performance.	2.9	Verify that equipment is being operated and maintained according to quality assurance standards .	2.9		X							
				Monitor equipment operation.	2.8								X	
		Monitor operations to ensure compliance with regulations or standards.	2.6	Monitor machine operation and control panel displays, and compare readings to specifications to detect malfunctions.	3.2								X	
				Check to ensure that workpieces are properly lubricated and cooled during machine operation.	2.4									X
				Read worker logs, product processing sheets, or specification sheets to verify quality assurance specifications.	2.6		X							

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Photonic T	Ind Eng T	ElecEng T	Chemical T	MechEng T	MechaTron T	CNC Oper	Machinists	
Inspecting Equipment, Structures, or Material	2.8	Test characteristics of materials or products.	3.7	Test products for performance characteristics or adherence to specifications.	3.7		X							
		Inspect completed work or finished products.	3.1	Inspect electrical project work for quality control and assurance.	3.7			X						
				Verify part dimensions or clearances to ensure conformance to specifications, using precision measuring instruments.	2.7						X			
		Test performance of equipment or systems.	2.5	Set up or operate test equipment to evaluate performance of developmental parts, assemblies, or systems under simulated operating conditions.	2.9			X						
				Develop, test, or program automated production equipment or other robotic systems.	2.5							X		
				Test performance of electromechanical assemblies, using test instruments such as oscilloscopes, electronic voltmeters, or bridges.	2.4							X		
				Test equipment, using test devices attached to generator, voltage regulator, or other electrical parts, such as generators or spark plugs.	2.2						X			
Data Collection & Synthesis	2.7	Read documents or materials to inform work processes.	2.7	Read blueprints, diagrams, or technical orders to determine methods of assembly.	3.0						X			
				Review project instructions and blueprints to ascertain test specifications, procedures, and objectives	2.8					X				
				Review program specifications or blueprints to determine and set machine operations and sequencing, finished workpiece dimensions, or numerical control sequences.	2.2							X		

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Photonic T	Ind Eng T	ElecEng T	Chemical T	MechEng T	MechaTron T	CNC Oper	Machinists	
Thinking & Making Creatively	2.5	Develop research plans or methodologies.	2.8	Plan method or sequence of operations for developing or testing experimental electronic or electrical equipment.	2.8			X						
		Design electrical or electronic systems or equipment.	2.7	Modify electrical prototypes, parts, assemblies, or systems to correct functional deviations.	3.0			X						
				Develop, test, or program automated production equipment or other robotic systems.		2.5						X		
		Design computer or information systems or applications.	2.7	Install or program computer hardware or machine or instrumentation software in microprocessor-based systems	2.7							X		
		Design industrial systems or equipment.	2.6	Fabricate and assemble new or modified mechanical components for products such as industrial machinery or equipment, and measuring instruments.	2.6						X			
		Create visual designs or displays.	2.1	Draft detail drawing or sketch for drafting room completion or to request parts fabrication by machine, sheet or wood shops.	2.2						X			
				Prepare charts or diagrams to illustrate workflow, routing, floor layouts, material handling, or machine utilization.	1.8		X							

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Photonic T	Ind Eng T	ElecEng T	Chemical T	MechEng T	MechaTron T	CNC Oper	Machinists
Analyzing Data or Information	2.5	Analyze biological or chemical substances or related data.	3.3	Set up and conduct chemical experiments, tests, and analyses, using techniques such as chromatography, spectroscopy, physical or chemical separation techniques, or microscopy.	-nr-				X				
				Conduct chemical or physical laboratory tests to assist scientists in making qualitative or quantitative analyses of solids, liquids, or gaseous materials.	-nr-				X				
		Analyze performance of systems or equipment.	2.3	Interpret test information to resolve design-related problems.	3.0			X					
				Compile and evaluate data using statistical process control procedures	2.1		X						
				Analyze test results in relation to design or rated specifications and test objectives, and modify or adjust equipment to meet specifications.	1.9					X			
				Analyze product failure data and laboratory test results to determine causes of problems and develop solutions.	-nr-								

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Photonic T	Ind Eng T	ElecEng T	Chemical T	MechEng T	MechaTron T	CNC Oper	Machinists
Information Management	2.4	Present research or technical information.	3.2	Write technical reports or prepare graphs or charts to document experimental results.	-nr-				X				
		Prepare documentation for contracts, applications, or permits.	2.8	Prepare, review, or coordinate ongoing modifications to electrical system specifications or plans.	2.8			X					
		Document technical designs, procedures, or activities.	2.2	Record test procedures and results, numerical and graphical data, and recommendations for changes in product or test methods.	2.5					X			
				Write procedures for the commissioning of electrical installations.	2.2			X					
				Prepare written documentation of electromechanical test results.	2.1						X		

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Photonic T	Ind Eng T	ElecEng T	Chemical T	MechEng T	MechaTron T	CNC Oper	Machinists
Making Decisions and Troubleshooting Problems	1.9	Determine operational methods or procedures.	2.6	Plan method or sequence of operations for developing or testing experimental electronic or electrical equipment.	2.8			X					
				Determine appropriate methods for fabricating and joining materials.	-nr-								
				Calculate machine speed and feed ratios and the size and position of cuts.	2.4						X		
				Prepare electrical project cost or work-time estimates.	1.4					X			
				Calculate required capacities for equipment to obtain specified performance	1.1						X		
Estimating and Judging the Characteristics of Products or Processes	1.7	Estimate project development or operational costs.	1.7	Estimate cost factors including labor and material for purchased and fabricated parts and costs for assembly, testing, or installing.	1.9					X			
				Prepare electrical project cost or work-time estimates.	1.4					X			

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Photonic T	Ind Eng T	ElecEng T	Chemical T	MechEng T	MechaTron T	CNC Oper	Machinists
Communicating with Supervisors, Peers, or Subordinates	3.1	Coordinate with others to resolve problems.	3.1	Collaborate with electrical engineers or other personnel to identify, define, or solve developmental problems.	3.1			X					
Performing General Physical Activities	2.7	Clean tools, equipment, facilities, or work areas.	2.7	Clean machines, tooling, or parts, using solvents or solutions and rags.	2.7							X	
Judging the Qualities of Things, Services, or People	2.3	Evaluate production inputs or outputs.	2.3	Monitor product quality to ensure compliance with standards and specifications.	-nr-				X				
Interpreting the Meaning of Information for Others	2.2	Explain technical details of products or services.	2.2	Interpret engineering drawings, schematic diagrams, or formulas for management or engineering staff.	2.2		X						
Organizing, Planning, and Prioritizing Work	1.9	Plan work activities.	1.9	Aid in planning work assignments in accordance with worker performance, machine capacity, production schedules, or anticipated delays.	1.9		X						
Evaluating Information to Determine Compliance with Standards	0.0	Assess compliance with environmental standards or regulations.	0.0	Review new product plans and make recommendations for material selection, based on design objectives such as strength, weight, heat resistance, electrical conductivity, and cost.	-nr-								

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