White Paper

Closing the Skills Gap in Engineering Education: A Multidimensional Perspective

David Pistrui, Derrell Kleinke, Shuvra Das, and Rochelle Mick
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Authors:

Dr. David Pistrui (University of Detroit Mercy and Automation Alley R&D),

Dr. Darrell Kleinke (University of Detroit Mercy and Automation Alley R&D),

Dr. Shuvra Das (University of Detroit Mercy and Automation Alley R&D),

Ms. Rochelle Mick (Automation Alley R&D)

Contracted by:

Mr. Tom Kelly, CEO
Automation Alley Research & Development Division
2675 Bellingham Rd, Troy, MI 48083

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Executive Summary

This research was commissioned by Automation Alley's Research and Development Division at the request of Autodesk, Inc. Several objectives were achieved by this work:

1) Developed a comprehensive understanding of the mechanical engineering and technology talent pipeline involving two- and four-year academic institutions.

2) Provided data-driven insights that can be used by technology providers to create strategies and tactics.

3) Examined the supply and demand dynamics that are shaping two- and four-year mechanical engineering and mechanical technology educational institutions.

4) Identified areas of opportunity for strengthening collaboration between technology providers and educational institutions.

5) Enumerated recommendations that technology providers, educators, and makers can use to drive strategies and tactics.

The report provides evidence that the mechanical engineering and technology talent pipeline is failing to provide sufficient quantities of Industry 4.0 workers. In addition, recent graduates of two-year and four-year programs lack the necessary training in professional skills, such as the ability to collaborate and effectively formulate problem statements. The need to change academic programs and to provide reskilling programs for the existing workforce has become ever more urgent. Reliable data collection instruments are essential to quantify the efforts to improve the Industry 4.0 talent pipeline.

The data insights show that significant generational differences are clearly evident in terms of behaviors, motivations, and competencies. The report provides data on three critical populations in the talent pipeline: 1) next-generation engineering students; 2) next-generation skilled tradespeople; and 3) next-generation engineering leaders. The data show that differences between the generations are having profound, negative impacts. Academic programs that worked for a past generation are no longer effective, and in some cases the data shows a worsening of important soft skills. To address this problem, an insightful approach is to consider academia as a classic supply and demand ecosystem.

Academic supply and demand dynamics are being disrupted by many challenges. On the academic supply side, confusing messages are being conveyed to a shrinking pool of prospects. Inside academic programs, Industry 4.0 technology breakthroughs are outpacing academia's ability to change. On the exit side, STEM graduates and newly minted two-year technicians are frustrated by the lack of academic progress when they realize they are not prepared to immediately contribute to their new employers. With entrepreneurial thinking, these problems become opportunities.

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Phone: 0049 7333-94265-0
Serial No.: 0200
Manufactured: 10/2018
FANUC ROBODRILL DDR
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Introduction

The cultural and technical forces associated with the Fourth Industrial Revolution, Industry 4.0, are unprecedented. The term "Industry 4.0" is now commonly used in reference to this revolution. Industry 4.0 is a result of the convergence of digital, biological, and physical technologies. Industry 4.0 dynamics are dramatically shaping the technical talent landscape. Simultaneously, cultural changes are being driven by generational transition. As the Baby Boomer generation (1946–1964) exits the workforce, the Millennial generation (1981–1996) and the Generation Z'ers (1997–2012) are rising up as the majority of the technical workforce.

This profound and dramatic transformation to the manufacturing industry is rooted in a unique combination of forces, including the velocity, breadth, and depth of change [1], and is shaping our talent pipeline. What are Industry 4.0's implications for industry and educators now and in the near future?

These disruptive market forces are driving the development of new business models that have great impact on the relationships between manufacturing, design, and the human interface. Industry 4.0 is also producing profound ramifications for businesses' cost structure, work process design, and the involvement of human labor to drive innovation and growth [2]. While some jobs will be eliminated, more importantly, new and different types of work will emerge. For companies, reskilling and upskilling strategies will be critical if they are to find the talent they need and deliver the work of the future.

In addition to the rapid advances in technology, there are also cultural forces shaping the employment landscape, principally generational transition as Baby Boomers retire and Millennials and Gen Zers become the primary workforce. These succeeding generations have a distinctly different set of perspectives and values as it relates to work, education, and life balance.

Educators will also be required to radically rethink their models, methods, and offerings to meet the needs of a rapidly changing society and industry. Nations that thrive and prosper will be the ones that bring industry, education, and policy makers together around common objectives, combined with the ability to be agile and reactive to continued disruption and change in the marketplace.

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Purpose

Today, a new set of working skills are required. To address the needs of human talent, which is critical to developing and retaining an Industry 4.0–ready workforce, industry and educators must go beyond simply reskilling and upskilling initiatives. What organizations must focus on are career strategies, talent mobility, and re-engineering ecosystems and networks to facilitate both individual and organizational reinvention [3].

This research builds on the work of Das et al. [4], Pistrui and Kleinke et al. [5–7], and Petrick and McCreary [8] to identify emerging trends, pinpoint challenges, and gain data-driven insights into the forces shaping the technical talent pipeline and to provide direction on how to improve and strengthen the talent pipeline.

Research objectives include:

1. Building on previous and ongoing research findings to provide a deeper and more comprehensive understanding of the talent pipeline, specifically as it applies to mechanical design and "making," which is the conversion of the theoretical into the practical.
2. Incorporating data-driven insights to produce new knowledge that can be used by technology providers to create strategies and tactics to strengthen their positions in the mechanical talent pipeline (two- and four-year institutions).
3. Examining the supply and demand dynamics that are shaping two- and four-year educational institutions' challenges to producing the quantities and qualities of talent industry needs.
4. Identifying areas of opportunity for strengthening the collaboration between technology providers and educational systems to close the skills gap and strengthen the talent pipeline.
5. Offering a series of concluding thoughts and recommendations that technology providers, educators, and makers can use to drive strategies and tactics to strengthen the talent pipeline.

Background Literature Review

Emerging Workforce Themes and the Talent Horizon in a Pandemic

To prosper in the Industry 4.0 ecosystem, individuals and organizations will be required to develop 21st-century skill sets. The talent pipeline is failing to provide sufficient quantities of workers and calls for stepping up Industry 4.0 reskilling have become ever more urgent [1]. Industry leaders, educators, and policy makers must accept that radically new ways of working are opportunities to embrace, not simply problems to solve [5].

The driving forces changing how we work and the jobs that we do will impact organizations of all sizes across all sectors. In addition, COVID-19 has created an economic situation that is fundamentally different from any previous crisis [9]. The global pandemic has accelerated the pace of change and disruption to a level not experienced before. The combination of Industry 4.0 and COVID-19 is creating a new sense of urgency to drive collaboration between industry and education.

The factories of the Industry 4.0 digital age are very different from the legacy operations of the automation age of Industry 3.0. In 2015 alone, nearly 100,000 robots were deployed in automotive factories and 65,000 more were installed in electronics factories as automation continued to reshape the

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size of the labor pool [10]. With the advent of Industry 4.0, each robot installation is also a digital installation as the robots are equipped with technologies such as machine learning, cloud computing, and big data. The work of the labor pool must evolve.

A recent study conducted by the Ralph C. Wilson, Jr. Foundation reports that in Southeast Michigan 30% of the middle skilled labor pool will be displaced by automation by 2030 [11]. There will also continue to be a shortage of workers with the skills industry is seeking. Many people will need to transition from "traditional careers" where they have trained to do specific tasks (e.g., mechanical engineer) to "multitrack careers" where they will have multiple simultaneous jobs such as engineer, data analyst, and network administrator [6,12].

Table 1 presents an overview of the emerging themes shaping the workforce environment. Four central themes are having dramatic impact on the Industry 4.0 work environment:

To successfully navigate the Industry 4.0 environment (and beyond), organizations will need to integrate four (and soon five) generations into their workforce. This will be no easy task given the generational differences coupled with the shortage of qualified talent.

Implications for Industry

Today, there is a significant shift from selling what exists to imagining what's next. Fifty years ago, the life expectancy of a Fortune 500 firm was around 75 years. Currently, it is less than 15 years and declining rapidly. Dynamic change and a disruptive consumer-oriented market economy are fueling these changes.

More than ever, even the largest companies risk being marginalized, commoditized, or disrupted. As well-funded startups and risk-embracing players seek to challenge prevailing paradigms and alter long-standing models, innovation has become critical, not merely for growth but for survival. As volatility, uncertainty, complexity, and ambiguity rise, disruptive and disintermediating transformation in products, services,

TABLE 1: **Emerging Workforce Themes**

1	2	3	4
The Workforce Must Embrace Frequent and Constant Change. Industry 4.0 is expected to significantly increase the pace of change. Companies need to be aware of the implications of disruption to their workforce.	**Teams Must be Flexible, Adaptive, and Collaborative.** Team agility, an entrepreneurial mindset, and the ability to persist through failure are fundamental to creating and sustaining networks of interrelated teams.	**Companies Must Create Cultures of Inclusion and Transparency.** This requires breaking down traditional hierarchies, implementing agile methodologies, and embracing the changing nature of work tasks.	**Workers Must Become Lifelong Learners and Dynamic Thinkers.** Dynamic thinking requires empathy, collaboration, experimentalism, and a focus on solving problems and creating value for other humans.

Sources: [1]; [6-7]; [13]; [5]; [11].

and offerings will continue to increase. Imagination and the creation of compelling experiences, radical brand evolutions and new business models will drive this revolution. Airbnb, Amazon, and Uber are examples of disruptive new innovative business models.

Innovation created around human-centric dynamic thinking will continue to emerge as critical survival skills and growth strategies. Generative research focused on gaining entirely new insights and inspirations that drive new offerings will become the strategic tool of choice for agile companies in a rapidly evolving marketplace.

In order to navigate the chaos and identify as well as capitalize on the disruptive opportunities associated with Industry 4.0, we must create a culture of dynamic thinkers across all levels of organizations large and small. This is paramount to sustain our leadership position locally, regionally, nationally, and on a global level.

Industry must find a new sense of urgency in this rapidly changing environment of technological disruption combined with the challenges of a global pandemic. This includes creating a robust network of teams that is empowered to operate outside of the current hierarchy and bureaucratic structures of the organization [14]. A culture of inclusion is key to effectively employing adaptive teams. For the "team of teams" approach to effectively function in the disruption of Industry 4.0, the organization must possess a shared consciousness.

Establishing and maintaining shared consciousness demands the adoption of extreme transparency throughout internal teams and external stakeholders [15]. This requires breaking down traditional hierarchies, implementing agile methodologies in the face of disruption due to emerging technologies and the changing nature of work tasks. Furthermore, people must be perpetual learners (often in real time) and think in new and dynamic ways [6].

TABLE 2: **Emerging Trends and Traits Shaping the Industry 4.0 Workforce**

Past Trends	Present Trends	Emerging Trends
Structured hierarchies	Networks of teams	Empowered agility
Static career	Dynamic longevity	Recreation and repurpose
Recruiting talent	Cognitive technologies	Matching talent to culture
Selection and retention	Employee journeys	Well-being and inclusion
Performance appraisals	Continuous feedback	Cultures of performance
Managerial hierarchies	Leading in rapid change	Dynamic thinking models
Digitizing platforms	Building digital organizations	Changing nature of work
Key performance indicators	People-centric analytics	Recalculating performance
Diversity through delegation	Diversity through process	Value creation via diversity
On balance sheet employees	Insourcing outside expertise	Open talent economy

Sources: [15]; [16]; [13]; [5-6].

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Educators are slow to react and are steeped in the legacy of the academy. Consequently, industry must take ownership of the moment and compel itself to assume both a leadership role and collaborative spirit in helping drive systemic education reform in order to compete and survive now and in the future. Industry needs to engage with both two-year and four-year educational institutions in new and dynamic ways, not to mention K–12 systems as well.

One thing is certain, people working collaboratively in new ways that require new skills and knowhow will be paramount to the success of industry and the well-being of society.

Insights into 21st–Century Industry 4.0 Skills, Mindsets, and Cultures of Performance

Research conducted by Pistrui et al. [5–7] provides insights into three categories and specific types of skills that industry and educators view as critical for the 21st century. Their research identified three categories of skills that are important to develop and employ in an Industry 4.0 environment, including discerning skills, people skills, and purposeful skills (see Table 3). These findings parallel the work of Petrick and McCreary [8], Bawany [17], Schwab [18], and Arena [13], who all identified similar skill sets, common trends, and empirical findings.

The need to develop discerning skills is a result of the disruption and uncertainties associated with Industry 4.0. This applies to both companies and educational institutions. People need to be able to identify patterns and make new connections in ways never imagined before. Moving forward, they must envision and create new products, efficient services, and better user experiences.

The research of Petrick and McCreary [8] included 404 manufacturing companies directly involved in creating and implementing smart technologies. The findings were similar to the work of Pistrui et al., reporting that creativity and innovation, the ability to be forward looking, and having an improvement mindset are all required to successfully navigate the digital transformation [5, p. 9]. Bawany [17] contends that a digital leader in an Industry 4.0 environment must build teams, keep people connected, and drive a culture of innovation [9, p. 107], which aligns with both Pistrui et al. [5–7] and Petrick and McCreary's [8] findings.

Good people skills impact organizations at all levels, from the executive suite to the shop floor. People are the key to success, and today there is a shortage of individuals to fill the jobs available in the marketplace. People skills can mean the difference between survival and failure. Communicating, listening, understanding, and embracing diversity along with building trust are critical to the success of both companies and educational institutions.

In their 2016 report "The Future of Jobs," the World Economic Forum identified core people skills as critical for success in the workforce, including people management, coordinating with others, and negotiation. The research of Petrick and McCreary [8] reports comparable findings with Pistrui et al., identifying similar people skills as vital including trust, empowerment, networking, and collaboration as central to developing a 21st–century workforce.

TABLE 3: **21st–Century Industry 4.0 Categories and Skill Types**

Discerning Skills Perceptive, astute, and discriminating aptitudes	**People Skills** Individual, team, and group effectiveness	**Purposeful Skills** Determination, aim, and need for achievement
Creativity and Innovation Creating new approaches, designs, processes, technologies, and/or systems to achieve the desired result.	**Interpersonal Skills** Effectively communicating, building rapport, and relating well to all kinds of people.	**Self-Starting** Demonstrating initiative and willingness to begin working.
Conceptual Thinking Analyzing hypothetical situations, patterns and/or abstract concepts to formulate connections and new insights.	**Understanding Others** Understanding the uniqueness and contributions of others.	**Continuous Learning** Taking initiative to regularly learn new concepts, technologies, and/or methods.
Futuristic Thinking Imagining, envisioning, projecting, and/or creating what has not yet been actualized.	**Teamwork** Cooperating with others to meet objectives.	**Negotiation** Listening to many points of view and facilitating agreements between two or more parties.

Sources: [5-8, 13, 17-18].

Strong, purposeful skills that include self-initiative and the need for achievement are essential to navigating the integration of learning new concepts and methods and employing new technologies. Arena [13] described the need to carve new paths toward breakthroughs within existing business models [11 p. 203]. In their work with 404 manufacturing firms, researchers Petrick and McCreary [8] reported that leaders believe that there is a need for risk taking and operating as "mavericks" in the transition into an agile digital enterprise [5 p. 7].

Researchers Petrick and McCreary [8], Bawany [17], and Pistrui et al. [5–7] reported that determination, challenging the status quo, and persistence through failure were traits, skills, and mindsets that are vital to effectively navigate an Industry 4.0 environment. Eminent Industry 4.0 scholar Schwab [1] advocated that people must be continuous learners in order to create and sustain innovative and collaborative organizations and cultures during the Fourth Industrial Revolution and beyond. Pistrui et al. [5–7] documented that listening, openness to new ideas, and respecting different points of view are vital to working effectively across generations (e.g., Baby Boomers, Gen Xers, and Millennials).

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Industry 4.0 Workforce Opportunities

For the most part, the employability skills components are not a part of a formal high school or college education today and represent an enormous opportunity for reform. What should these new combinations of skills look like in order to prosper in an Industry 4.0 environment? Table 4 provides a series of workforce development snapshots relating to four different areas. These were created by reviewing a series of reports from the Workforce Intelligence Network (WIN) and World Economic Forum in combination with empirical research and structured interviews conducted by the authors of this report.

Universities are only now beginning to update curriculum to address these new technological needs, usually through certification programs (up-skilling) and concentrations such as mechatronics and data analytics (new combinations). The lack of well-developed employability skills can stymie innovation, collaboration, teamwork, and job performance. The disruptions associated with Industry 4.0 and COVID-19 are forcing both

TABLE 4: **Industry 4.0–Focused Workforce Development Snapshot**

CONNECTED & AUTONOMOUS VEHICLES	CYBERSECURITY	ADVANCED MATERIALS	MOBILITY PRODUCT DEVELOPMENT
TECHNICAL SKILLS · Software & Application Developement · Information Security Analysis · Computer Systems Engineering · Electrical Engineering · Computer Systems Analysis	**TECHNICAL SKILLS** · Advanced Software Skills · Information Systems · Information & Network Security · Technical Support · Cryptography	**TECHNICAL SKILLS** · Chemical & Material Science · Composites Knowledge · Manufacturing Skills · Engineering & Computer Skills · Skilled Trades Knowhow	**TECHNICAL SKILLS** · Systems Engineering · Systems Architecture · Engineering & Computer Systems · Information Technology Networks · Materials Science & Manufacturing
EMPLOYABILITY SKILLS · Creativity & Innovation · Futuristic Thinking · Problem Solving · Teamwork · Communication Skills	**EMPLOYABILITY SKILLS** · Communication Skills · Problem Solving · Teamwork · Collaboration · Planning & Organizing	**EMPLOYABILITY SKILLS** · Multidisciplinary Skills · Communication Skills · Conceptual Thinking · Teamwork · Continuous Learning	**EMPLOYABILITY SKILLS** · Creativity & Innovation · Futuristic Thinking · Interpersonal Skills · Business Acumen · Communication Skills

Sources: [5, 19-22].

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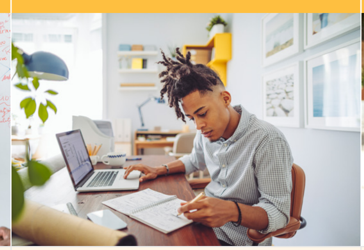
industry and educators to in essence reset, recalibrate, and create new types of collaborative partnerships.

Generational Transition and Leadership Succession

Socio-cultural transformation is a challenge confronting both industry and education due to each generation's radically different views on work-life balance, the loss of knowledge through Baby Boomer retirement, and a global shortage of qualified talent. Generation X now holds 51% of management and leadership positions. With an average of 20 years of workplace experience, they are primed to quickly assume nearly all top executive roles [23]. Not far behind are the Millennials, who represent the largest segment of the working population.

Gen Zers are now joining the workforce in entry level positions. They are a generation with their own unique attributes that include being very inclusive in nature. They are also found to rally around causes. They believe profoundly in the efficacy of dialogue to solve conflicts and improve the world. Gen Zers

FIGURE 1: Generational Birth Years, Traits Strengths, and Challenges*

BABY BOOMERS 1946-1964	**GENERATION X** 1965-1980	**MILLENIALS/GEN Y** 1981-1996	**GENERATION Z** 1997-2012
			
STRENGTHS	**STRENGTHS**	**STRENGTHS**	**STRENGTHS**
Work-centric/career-driven	Results and efficiency focus	Excellent technical skills	True digital natives
Independent and self-reliant	Metrics and data-driven	Can-do attitude	Radically inclusive
High level of competitiveness	Conventional leadership style	Excellent multi-taskers	Mobilizers around causes
CHALLENGES	**CHALLENGES**	**CHALLENGES**	**CHALLENGES**
Supports hierarchical thinking	Forgotten generation	Lacking professional loyalty	Requires constant feedback
Believes in face time at office	Works to live vs. lives to work	Quickly bored and frustrated	Little delineation between work and home
Aggressive & confrontational	Lack of process focus/skills	Enjoys working remotely	Can be focus-challenged

*We use the Pew Research generational classification system (other generational classification systems may very) [24].
Sources: [6, 16, 24, 25, 26, 27, 28].

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make decisions and relate to institutions in highly analytical and pragmatic ways [27]. Their world is rooted in mobility and multiple realities. In 2017, O'Boyle, et al. [28] reported that many Gen Zers expressed concern that technology is weakening their ability to maintain strong interpersonal relationships and develop people skills. This is a shortcoming that organizations should be aware of as Gen Zers enter the workforce.

Data Driven Investigation of Three Sectors of the Talent Pipeline

Drawing on a series of proprietary data sets developed over the past four years, this research represents a snapshot of the U.S. that is being intensely disrupted by both the technical and cultural forces associated with Industry 4.0 and a multi-generational workforce. Research conducted in partnership with TTI Success Insights investigated three key segments of the talent pipeline:

1. Next-Gen Leaders (NGLs): Engineers from OEMs and Tier 1 suppliers who have been identified by their companies as emerging leaders in their organizations. This group is composed primarily of Gen Xers and Millennials who have master's degrees.
2. Next-Gen Engineers (NGEs): Undergraduate engineering students who are in their freshman and junior years in mechanical and electrical studies. This group represents Gen Zers.
3. Next-Gen Skilled Trades (NGSTs): Individuals enrolled in two-year skilled trades programs such as robotics, cybersecurity, and engineering technologies. They represent a cross section of generations but are primarily Millennials and Gen Zers.

Methodology and Research Instrument

To collect data, our research team partnered with TTI Success Insights, a 30-year-old Scottsdale, Arizona–based firm that serves clients in 90 countries and 40 languages. The firm is the global leader in providing research-based validated compliant assessment and coaching tools that enable organizations to meet their talent management needs. Their client base includes Fortune 500 companies, government agencies, and educational institutions around the world.

For data collection, the TTI TriMetrix® DNA assessment suite was used. The TTI TriMetrix® DNA assessment suite comprises three self-reporting assessment instruments that are administered via an online portal. Each of the three self-reporting assessment instruments are independently validated. The authors have administered over 10,000 TTI TriMetrix® DNA assessments relating to engineering education and professional development. There have been a series of peer reviewed research papers published using the TTI TriMetrix® DNA assessment suite that investigate engineering education and professional development.

Drawing from a data sample of 4,965 undergraduate students, and 313 entrepreneurially minded engineers, the work of Pistrui et al., [29] employed the TTI TriMetrix® DNA in a combination of descriptive and multivariate methods and techniques that quantified specific behavioral attributes and professional competencies found in entrepreneurially minded engineers. The doctoral dissertation research of Dietrich [30] was able to quantitatively distinguish between engineers and entrepreneurially minded engineers in both behavior and mastery of professional skills in the workplace. Research by Pistrui et al. [31] used the TTI TriMetrix® DNA assessment suite to define and establish a measurement model of undergraduate engineering education learning outcomes associated with professional competencies (soft skills) development.

FIGURE 2: TTI TriMetrix® DNA Assessment – Competencies, Behavioral Style, and Motivators

COMPETENCIES DEVELOPMENT INDICATOR – Data-Driven Insights – Twenty-five areas of one's personal and professional competencies	
BEHAVIORAL STYLE **– Knowledge of Self –** How one interacts in group and team settings	**MOTIVATORS** **– What Drives Your Actions –** Understand one's actions and the causes of conflict

Source: [7].

TTI TriMetrix® DNA assessments are used by organizations for professional development and social science research. The TTI TriMetrix® DNA assessment suite is designed to increase the understanding of an individual's DNA in three distinct areas: competencies, motivators, and behavioral styles. Understanding strengths and weaknesses in each of the three areas will lead to personal and professional development and a higher level of personal satisfaction. For this research, the TTI TriMetrix® DNA assessment was administered online between the fall of 2017 and the summer of 2020, with 473 individuals participating in the study: 66 NGLs, 182 NGEs, and 225 NGSTs. The sample is composed of 349 (74%) males and 124 (26%) females.

Females play an important role in the talent pipeline, representing 29% of the NGST and 26% of NGE. However, when it comes to NGLs, females trail off to 17%. There is cause for concern that perhaps either in perception or reality there are fewer opportunities for females to advance into management positions. This is an area worthy of further investigation and analysis beyond the scope of this work.

The TTI mean is a sample of all the individuals who have taken the TTI TriMetrix® DNA assessment suite. This is a national sample across all job sectors and allows for a general comparison.

Professional Competencies

Based on responses to a series of questions, this section presents an overview of the development of 25 professional competencies that contribute to superior performance in many types of jobs. For many jobs, professional competencies, often referred to as "employability" skills, are as important as technical skills in producing superior performance. Professional competencies are developmental and transferable to a variety of professions, whereas technical skills are usually job specific.

Figure 3 presents a comparative visual overview of the 25 professional competencies of each segment of the talent pipeline as compared to the TTI mean, a sample of all the individuals who have taken this survey across all job sectors. As expected, the Next-Gen Leaders exhibit the greatest level of professional competency development. They also have the

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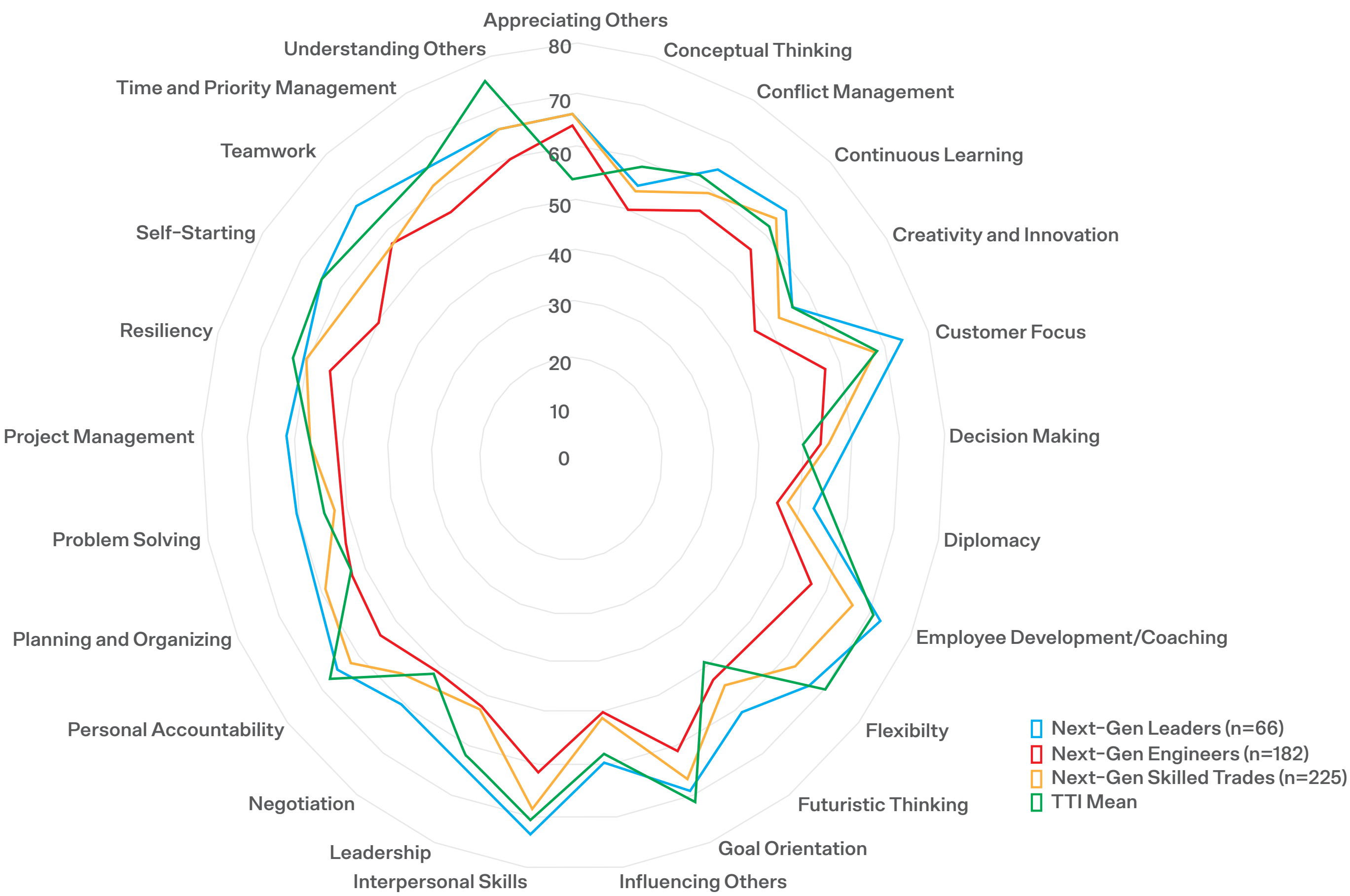
FIGURE 3: **Professional Competencies vs TTI Mean**



greatest level of experience and highest level of education. They have very well-developed interpersonal skills combined with a strong customer focus.

Next-Gen Engineers are young and in their formative years, and their level of professional competency development reflects this. They are found to be goal oriented and to demonstrate some level of interpersonal skills. The Next-Gen Skilled Trades people comprise multiple generations and thus represent a more eclectic and diverse set of individuals. They demonstrate strong interpersonal skills and show appreciation for others.

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TABLE 5: Competency Strengths and Weaknesses of the Talent Pipeline vs TTI Mean

	Next-Generation Leaders (NGL)		Next-Generation Engineers (NGE)		Next-Generation Skilled Trades (NGST)	
	Average	TTI Mean	Average	TTI Mean	Average	TTI Mean
TOP 3						
1	Customer Focus: 75	63	Appreciating Others: 65	55	Interpersonal Skills: 69	71
2	Employee Development: 73	72	Interpersonal Skills: 62	71	Customer Focus: 68	69
3	Interpersonal Skills: 74	67	Goal Orientation: 61	72	Appreciating Others: 68	72
BOTTOM 3						
1	Creativity & Innovation: 56	56	Self-Starting: 50	64	Problem Solving: 52	54
2	Conceptual Thinking: 55	59	Creativity & Innovation: 47	56	Influencing Others: 51	58
3	Diplomacy: 53	56	Diplomacy: 45	56	Diplomacy: 47	56

Two or more standard deviations above the mean (NGL Customer Focus 75)

One standard deviation above the mean (NGE Interpersonal Skills 62, Goal Orientation 61, Self-Starting 50, Creativity & Innovation 47, Diplomacy 45; NGST Interpersonal Skills 69, Customer Focus 68, Problem Solving 52, Influencing Others 51, Diplomacy 47; NGL Conceptual Thinking 55, Diplomacy 53)

One standard deviation below the mean (NGL Employee Development 73, Interpersonal Skills 74; NGE Appreciating Others 65; NGST Appreciating Others 68)

NGL n = 66, NGE n = 182, NGST n = 225

Next-Gen Leaders

Table 5 provides a deeper look into the professional competencies associated with each segment of the talent pipeline and compares the average competency by segment to the mean of all people who have taken the same suite of TTI TriMetrix DNA assessments (hundreds of thousands of people across all professions). The intention is to get a benchmark comparison of each segment against an aggregate mean of all professions. This is directional in nature and will be used to guide more deep and rigorous analysis of the data sets in the future.

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The Next-Gen Leaders were found to be well positioned to lead their organizations into the future. This group, which is composed of a mix of Gen Xers and Millennials, is customer-centric and demonstrates the ability to help others develop and grow. As one might expect, they have well-developed communication skills and possess the ability to interact and relate with others.

Turning to the three least-developed skills, it is eye-opening to learn that this group, the future leaders, score low on creativity and innovation. Being able to effectively create new approaches, designs, processes, technologies, and systems will be imperative for companies to navigate the disruption associated with Industry 4.0. The same can be said for conceptual thinking. Electrification and autonomous vehicle development (not to mention new business models) requires analyzing hypothetical abstract concepts and formulating connections and new insights.These findings provide insights for educators and industry leaders to review, refine, and reform educational practices to address these deficiencies both in the schools and respective companies. These findings suggest that topics such as design thinking, creativity, social science, and systems engineering should be integrated into all levels of education and across engineering curriculums.

Next-Gen Engineers

Next-Gen Engineers, composed of Gen Zers who are all undergraduate engineering students, represent the next generation of engineering talent. Table 5 indicates this group has their own set of unique strengths. The top two professional competencies they have developed at this stage in their lives seem to align with their generational tendency to be radically inclusive. This includes identifying with and caring about others. They exhibit the abilities of building rapport and relate well to different kinds of people. It is not a surprise that this group is goal oriented, given the intensity and rigor associated with earning an engineering degree.

There is some cause for concern when reviewing the least-developed professional competencies in the Next-Gen Engineering segment. The data suggests that they lack the ability to demonstrate self-initiative. Today's work environment with rapid change and disruption demands an opportunity-seeking mentality and self-drive. This is also a point of potential conflict between Gen Zers and Gen Xers. Just as the Next-Gen Leaders segment scored low on creativity and innovation, the Next-Gen Engineers do as well. The fact that both groups score so poorly in this area should be a wake-up call for both educators and industry leaders to begin to address these needs.

These findings suggest that educators and industry leaders should join forces to review current curriculum methods and develop an action plan to strengthen the creativity and innovation skills in both students and faculty.

Next-Gen Skilled Trades

Next-Gen Skilled Trades people demonstrated strong development of three primary professional competencies. First, they exhibit solid interpersonal skills associated with effectively communicating, building rapport, and relating to a diverse group of people. Second, they were found to have developed a customer focus with the skills to anticipate and meet customers' needs, wants, and expectations. Third, Next-Gen Skilled Trades people were found to be appreciating of others, having the ability to identify with and care about others. These findings reflect that this segment of the talent pipeline is often working and attending school part-time. They represent a cross section of generations and socioeconomic strata and are a vital part of the talent pipeline.

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In terms of least-developed professional competencies, three items emerged. The Next-Gen Skilled Trades group lacks problem-solving skills associated with defining, analyzing, and diagnosing key components of a problem to formulate a solution. Although they have strong interpersonal skills, they have underdeveloped abilities to influence others. Personally, they are weak at affecting others' actions, decisions, opinions, or thinking. Lastly, they lack diplomacy as they struggle with the ability to effectively and tactfully handle difficult or sensitive issues.

These insights suggest that community colleges have both the need and opportunity to review, recalibrate, and redirect programs to improve Industry 4.0 skill sets. As skilled trades continue to transform around Industry 4.0 technologies, the workforce will most certainly need better problem-solving competencies. Further, as skilled trades become more collaborative in nature (think robotics, the Internet of Things (IoT), cloud computing, and Big Data intersections) the workforce will be confronted with a different set of human interaction. New types of working relationships will require the ability to influence others with diplomacy, especially across and between generations.

Professional Competencies Below the National Mean

There are five professional competencies that the Southeast Michigan data set scores below the TTI mean. Three noteworthy themes emerge out of the data (see Table 5). 1) They score below the mean as it relates to understanding the uniqueness and contributions of others. 2) They score lower on conceptual thinking. Conceptual thinking relates to identifying patterns and formulating connections and concepts. 3) They score lower on personal accountability. These findings suggest that our emerging talent pipeline is more rigid, light on sensitivity (empathy), and less focused than the TTI mean. These are important distinctions in an Industry 4.0 environment and cause for educators and industry leaders to address these important needs.

These findings provide some valuable insights and direction into what educators and industry and policy makers should begin to address. For example, how can our educational system begin to develop measurable ways and methods to improve the conceptual thinking skills in their graduates? As the workforce proceeds through generational leadership succession, how can both industry and educators help people empathize and embrace the uniqueness and contributions of others? This is vital to strengthening the talent pipeline.

These findings suggest that instilling a broader goal orientation and personal and professional development must become core components of strengthening the quality of the workforce. With these newfound insights, educators, industry leaders, and government officials should review existing workforce development programs and initiatives to determine if these deficiencies are being addressed and begin immediately to formulate strategies and secure funding to address these core Industry 4.0 skill deficiencies.

Behavioral Styles

For this research, we utilized DISC, a behavior assessment tool based on the theory of psychologist William Moulton Marston. DISC centers on four different behavioral traits: Dominance, Influence, Steadiness, and Compliance. There are no best styles and all people exhibit some level of each style.

TABLE 6: Behavioral Strengths and Weaknesses of the Talent Pipeline vs TTI Mean

	Next-Generation Leaders (NGL)			Next-Generation Engineers (NGE)			Next-Generation Skilled Trades (NGST)		
		Average	TTI Mean		Average	TTI Mean		Average	TTI Mean
TOP 3	Competitive:	59	49	Persistent:	67	61	Consistent:	68	61
	Customer-Oriented:	59	64	Consistent:	66	61	Persistent:	68	61
	Persistent:	59	61	Following Policy:	64	60	Following Policy:	66	60
BOTTOM 3	Organized Workplace:	53	51	Urgency:	41	43	Urgency:	37	43
	Urgency:	54	43	Frequent Change:	48	52	Competitive:	46	49
	Analysis:	55	53	Versatile:	48	54	Frequent Change:	46	52

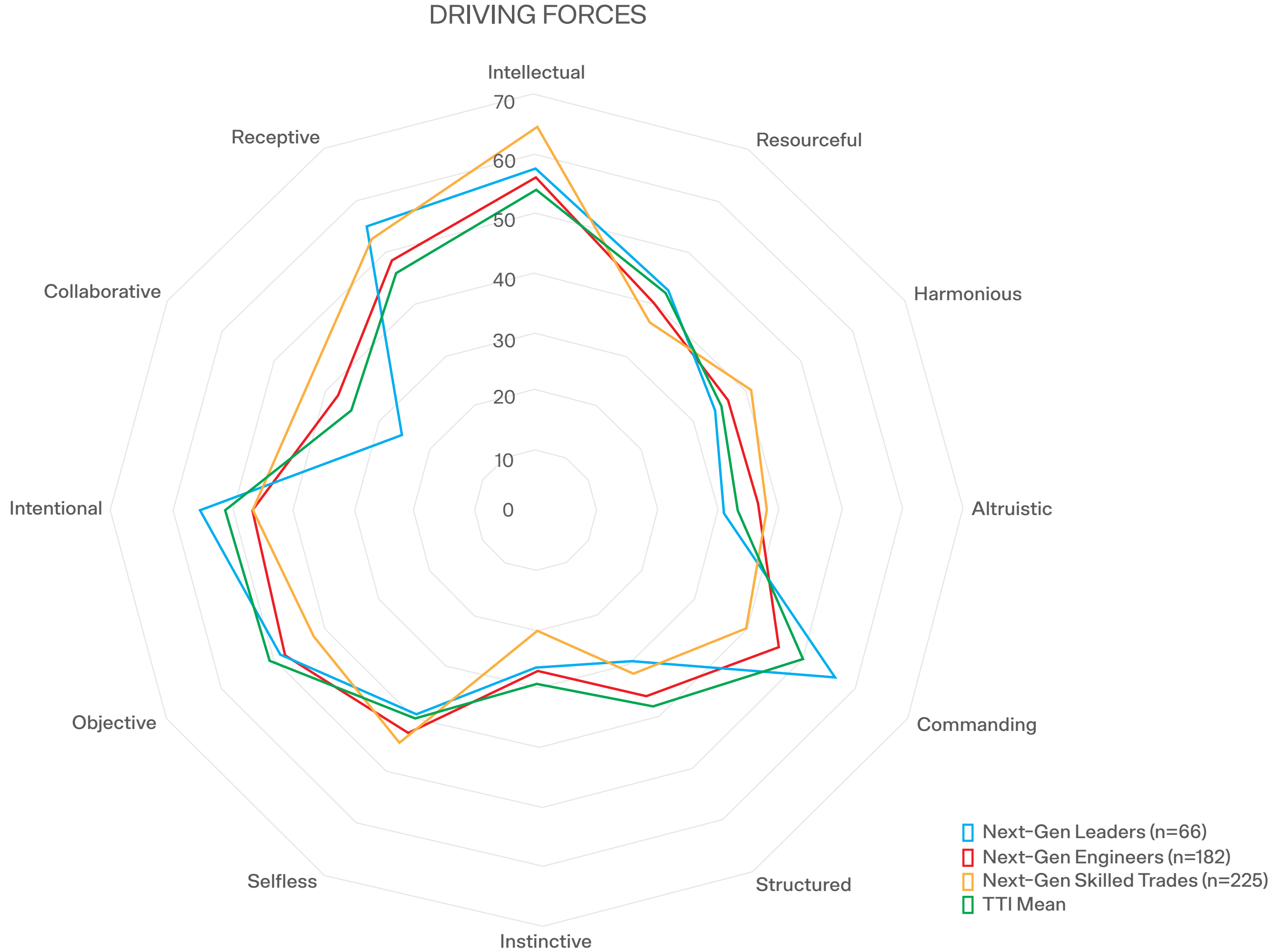
One standard deviation above the mean

One standard deviation below the mean

NGL n = 66, NGE n = 182, NGST n = 225

Understanding behavioral styles can help in gaining the commitment and cooperation of others, resolve and prevent conflict, build effective teams, and enhance awareness and personal performance. People exhibit both natural behavioral styles (the ones we wake up with in the morning) and adapted behavioral styles (the ones related to our environment, level of stress, and job requirements). Table 6 presents an overview of each segment's behavioral styles.

FIGURE 4: **Motivational Factors vs TTI Mean**



Motivational Factors

Motivators are the driving forces or the "why" of what we do. Understanding motivators provides insights into what drives people's actions in personal and professional settings. Primary motivators can be referred to as the aspects of life for which one is passionate and perceived as important, or the thoughts that provide one with purpose and direction in life. This research defines 12 motivational factors (see Figure 4).

TABLE 7: **Motivational Strengths and Weaknesses of the Talent Pipeline vs TTI Mean**

Next -Generation Leaders (NGL)			Next-Generation Engineers (NGE)			Next-Generation Skilled Trades (NGST)		
TOP 3			**TOP 3**			**TOP 3**		
	Average	TTI Mean		Average	TTI Mean		Average	TTI Mean
Intellectual:	57	54	Intellectual:	56	54	Intellectual:	64	54
Commanding:	56	50	Receptive:	58	46	Receptive:	53	46
Intentional:	55	51	Objective:	47	50	Intentional:	46	51
BOTTOM 3			**BOTTOM 3**			**BOTTOM 3**		
	Average	TTI Mean		Average	TTI Mean		Average	TTI Mean
Collaborative:	26	35	Instinctive:	27	29	Instinctive:	20	29
Instinctive:	26	29	Structured:	36	38	Structured:	31	46
Structured:	29	38	Altruistic:	37	33	Resourceful:	37	42

One standard deviation above the mean
One standard deviation below the mean

NGL n = 66, NGE n = 182, NGST n = 225

Next-Gen Leaders

Table 7 provides a comparative overview of the motivational factors shaping the talent pipeline. The Next-Gen Leaders are found to be commanding but not very collaborative. They are driven by status, recognition, and control over others. They are not motivated to play a supporting role if given a choice.

Next-Gen Engineers

As one might expect, the Next-Gen Engineers, who are undergraduate engineering students, are driven by the functionality and objectivity of their surroundings. They are in a rigorous, structured, and demanding environment, so this driving force is critical to achieving their degree. This group is also receptive to new thoughts and ideas but are driven only by practical results. They are driven to assist others for a specific purpose, not just for the sake of being helpful or supportive. It is also not surprising that Next-Gen Engineers do not score higher in resourcefulness. This is a result of being in an academic environment that has yet to adopt new methods that fall outside a defined system for learning.

Next-Gen Skilled Trades

The Next-Gen Skilled Trades group has some surprising and insightful motivators. First, they were found to be intellectually driven by opportunities to learn and acquire knowledge and had the highest level of motivational intensity. This may be due to the fact that they could be working full-time while pursuing their education. Counter to this, Next-Gen Skilled Trades people were also found to be much less instinctive, whereby they can utilize past experiences and intuition.

As students, they are seeking new knowledge and skills that can be used to improve their everyday lives and those of their families. Another interesting insight from this group is that they are not driven to achieve practical results through maximizing both efficiency and returns for their investments of time. This suggests that this group may be searching for opportunities that are not clear or well defined.

Motivational Factor Common Threads

Patterns emerge between the three groups when looking closely at motivational factors. All three segments are driven by an intellectual quest. They are motivated by opportunities to learn and acquire knowledge. This is encouraging as the integration of Industry 4.0 technologies demand intellectual curiosity and engagement. The Industry 4.0 disruption and rapidly changing environment requires continuous learning and the development of new skills.

Another commonality is that both the Next-Gen Engineers and the Next-Gen Skilled Trades groups are receptive to new ideas, methods, and opportunities that fall outside a defined system. This would seem logical, as both groups are in school. The same logic holds true for the Next-Gen Leaders who are driven by status, recognition, and control over personal freedom. Conflict could arise between Next-Gen Leaders, who have a drive to command and control, and the Next-Gen Engineers and Next-Gen Skilled Trades people who are motivated to pursue new ideas, methods, and opportunities.

Another common thread is that all three segments are indifferent to traditional approaches, proven methods and a defined system. Perhaps this is the result of the Industry 4.0 environment where change is constant, and people are being forced to adopt new methods and adapt to a changing work environment. This may also reflect generational differences where certain groups want to “do it their way.”

A Call for Education Workforce Development Reform and Additional Research

To successfully navigate the Industry 4.0 environment (and beyond), organizations will need to integrate four different generations (soon to be five) into their workforce. Next-Generation Leaders were found to be lacking in creativity and innovation and conceptual thinking, critical skills required in navigating an Industry 4.0 environment. This should serve as a wake-up call to educators tasked with overhauling an antiquated system, particularly at the graduate level.

Next-Generation Engineers (currently in the higher education system) are trending low in the categories of resourcefulness, creativity, and innovation. They were also found not to be self-starting or instinctive. This may be a result of an education system (K–12 and higher education) that has yet to fully

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TABLE 8: **Industry 4.0 Education Workforce Development Reform Framework**

Engineering and Science · Systems engineering & architecture · Advanced software skills & programming · Artificial intelligence & machine learning	**Business Acumen** · Entrepreneurial thinking & leadership · Industrial economics & data analytics · Financial management & decision making
Social Science · Sociology & anthropology · Industrial psychology · Research methodologies	**Creative Studies** · Design thinking methods · Innovation in society · Creativity & opportunity identification

Source: [7].

appreciate, embrace, and adapt to the rate of Industry 4.0 technology change and generational differences.

Next-Generation Skilled Trades is a group that is vital, yet often overlooked. They were found to be greatly lacking when it comes to problem-solving skills and the ability to influence others. They were also found to be lacking competitiveness, which suggests that educators need to rethink how they create dynamics between individuals, teams, and groups, and how industry rewards performance. These findings provide some direction to community colleges and labor organizations as they calibrate for an Industry 4.0 world.

Findings suggest that educators, industry leaders, and policy makers need to collaborate and initiate immediate and sweeping educational reform. Table 8 presents a suggested framework that recommends a transdisciplinary approach that will fundamentally change the focus, learning outcomes, and education of university and community college students in the U.S.

Engineering and science need to incorporate contemporary Industry 4.0 subject matter, such as advanced software skills and artificial intelligence, at the reduction of some Industry 2.0 subject matter, such as differential equations with linear algebra. This is not to say students should not be exposed

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to understanding differential equations, but they should be exposed to it in Industry 4.0–applied ways. Students should also be skilled in areas that promote the development and application of business acumen, including the intersections of entrepreneurial thinking and leadership, as well as data analytics, decision making, and financial economics. These will be essential as new business models unfold and are created.

Industry 4.0 workforce development reform also needs to re-incorporate the social sciences Sociology, anthropology, psychology, and the research methodologies these fields employ are other important areas in need of re-integration. Some of these topics could be one- or two-credit offerings that blend human engagement, online modules, readings, and field experiments. The data suggest that students could benefit from better understanding of human beings and culture.

Design thinking, which is currently a topic of much discussion in industry, should play a more distinctive role in Industry 4.0 educational experiences. The history and role of innovation in society, developing creativity, and identifying, qualifying, and quantifying socioeconomic opportunities need to become core principles of our educational frameworks at all levels.

This work serves not as an "end-all and be-all," but rather as a preliminary step, in one of many, to look at both the technical dynamics associated with Industry 4.0 and the human dynamics associated with generational transition and leadership succession in conjunction with the talent pipeline. While this research is independent, empirical, and rigorous, we advocate for an expansion of this work nationally, employing additional and more rigorous research methods, larger data sets, and transdisciplinary collaboration and analysis.

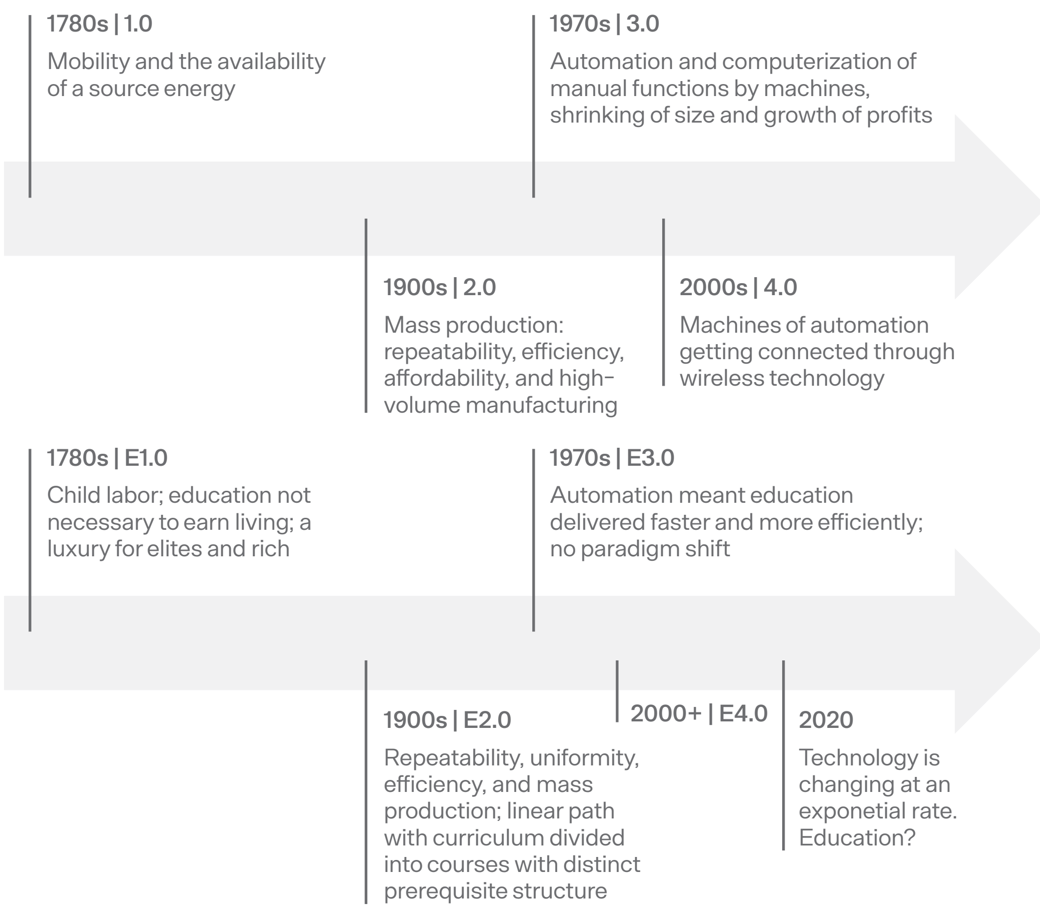
The Nature of the Challenge: The Skills Gap is Widening

The skills gap is widening as Industry 4.0 technology change outpaces academia's ability to react.

Technology is advancing at a faster rate than at any other time in history. The rate at which technology is evolving is outpacing academia's ability to incorporate new technology into the undergraduate and technician curriculum. But it is that curriculum that is the source of the next-generation workforce.

The transition from Industry 1.0 to 2.0 took almost a century and a half; the time between Industry 2.0 and 3.0 was a few decades; and the transition from Industry 3.0 to 4.0 was even shorter. This shrinking of periods between transformations was driven by the pace of technological change. At the moment, technological changes are happening at an exponential rate and Industry 4.0 is destined to change a lot of things in ways that are unfathomable.

FIGURE 5: **Pace of Change in Technology and in Education**



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All these industrial revolutions did not just influence industrial productivity, but the labor market and the educational system were also altered permanently. As a result of these changes, some professions and jobs have disappeared. Currently, due to the development of digitalization and robotics, we are facing a similar era of change. "We are currently preparing students for jobs that don't yet exist, using technologies that haven't been invented, in order to solve problems we don't even know are problems." Most of us have come across this famous insight from former U.S. Secretary of Education, Richard Riley. Below are some recently reported findings and thoughts related to the future of work [32]:

- 65% of children entering elementary school this year will work in a job that hasn't yet been invented.
- 49% of current jobs have the potential for machine replacement, with 60% having at least one-third of their activities automated.
- 80% of the skills trained for in the last 50 years can now be outperformed by machines.
- At a global level, technically automatable activities touch the equivalent of 1.1 billion employees and $15.8 trillion in wages.

"The emerging technologies have a huge effect on the education of people. Only qualified and highly educated employees will be able to control these technologies." [33]

"The argument is simple: the change is here, there's no avoiding it, so it's time to adapt. Institutions must change to keep up—and I don't mean they need reform; there's no use in improving a broken model. We are on the brink of a Fourth Industrial Revolution, and we need a full-scale transformation, an education revolution to keep up to the world of 4.0." [32]

"Education 4.0 is catering to the needs of society in an 'innovative era.' It is in accordance with the changing behavior with the special characteristics of parallelism, connectivism [33], and visualization. This learning management must help to develop the learner's ability to apply the new technology, which will help the learner to develop according to the changes in society. Learning management of this era is a new learning system, allowing the learner to grow with knowledge and skills for the whole life, not just to know how to read and write. To be able to live in a society and to be equipped with the best of his/her ability. Therefore, Education 4.0 will be more than just an education." [34–35]

"Our students will have to succeed in a working environment which is increasingly globalized, automatized, virtualized, networked and flexible. Many jobs, such as Social Media Manager, Blogger, App Designer, App Developer, Big Data Analyst seem quite conventional to us today. However, they did not exist 10 years ago and these are not purely "digital" jobs either: they require a sound knowledge in the field of application as well." [36]

"Education 4.0 is a response to the needs of IR4.0 where human and technology are aligned to enable new possibilities. Fisk explains that the new vision of learning promotes learners to learn not only skills and knowledge that are needed but also to identify the source to learn these skills and knowledge. Learning is built around them as to where and how to learn and tracking of their performance is done through data-based customization. Peers become very significant in their learning. They learn together and from each other, while the teachers assume the role of facilitators in their learning." [37]

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Allen [38] discusses how manufacturers are producing "47%more than they did 20 years ago, with 29% fewer workers." "Technology is no longer automating manual labor, it's automating cognition." The old playbook for education is not going to prepare students for automation. "Our education system is still preparing students for jobs that soon won't exist."

"As manufacturing integrates industry 4.0 technologies, more manufacturing jobs will require degrees and companies to invest in their employees. On top of hard skills, Azizul states that "management has to be supportive, not aggressive. If you want to retrain (staff), you have to assess their capacity and ability." [39]

Technical universities not only face the costs associated with exponentially growing technology, they also wrestle with the same social and economic issues faced by non-technical schools. A watchdog group called the "Education Dive Team" [40] has been tracking university closures over the last four years. They cite the following factors: "Pressure to lower tuition, stagnating state funding, and a shrinking pool of high school graduates has strained many institutions' bottom lines and questioned their long-term viability. Those pressures have caused some to close." Of course, the coronavirus pandemic has made the situation even worse. "For many still in operation, the coronavirus pandemic and its economic impact is adding a host of uncertainties to already tight operations." A chronology and details of school closings can be found at "A Look at Trends in College and University Consolidation Since 2016" by the Education Dive Team. [40]

The schools are not the only ones facing financial pressures. Students are perhaps more sensitive than ever to the debt they must incur to attend college. While the cost of education has increased by over 150% over the last 40 years, minimum wage has not kept pace. Students who must work while going to school therefore find it harder and harder to make ends meet as well as go to school.

Research also shows that the government financial aid programs that are currently in place do not function in a way that could serve the real needs of students. Many of these programs have regulations that end up harming students rather than helping them. This leads to two types of challenges: students graduating with a degree and a huge debt; and students dropping out without a degree but with a large debt. While the former is troublesome, the latter is even worse because the students end up with a financial burden and nothing to show for it [41]. Essentially the financing of college education needs to be overhauled to make it effective and useful for all people.

Table 9 shows how tuition has changed in private and public institutions over the years. As this quote from Emmie Martin [42] states, "To put those numbers into perspective, a 1988 graduate of Harvard University would have spent $17,100 on tuition during their senior year. Now, in their 50s, they'd have to pay $44,990 in tuition for their child to attend Harvard today. That makes the current cost more than two-and-a-half times as much as it was in 1988—a markup of 163%. In 2012, 71% of graduates from four-year colleges carried debt, with students at public schools owing an average of $25,550 and those with degrees from private colleges owing an average of $32,300." [42]

TABLE 9: Change in College Tuition Over the Years

	Tuition in private nonprofit four-year institution	Tuition in public four-year institution
1987-1988	$15,160	$3,190
1997-1998	$21,020	$4,740
2007-2008	$27,520	$7,280
2017-2018	$34,740	$9,970

Source: [42].

Community colleges struggle to attract students to the trades, as automation and digitization threaten the traditional skilled-trades. The promise of a good paying secure job has been overshadowed by lack of employee/employer loyalty and the risk of obsolescence. The authors' studies of generation transition (discussed above) show that even the students currently representing the next-generation skilled trades are constantly looking for new opportunities and are less interested in traditional repetitive tasks. This is further backed by a professional service firm, Sikich, that claims from their experience: "Millennials grew up in a time of technological advancements in a hyper-connected society. Millennials are a generation influenced by digital media. With this being said, Millennials in the workforce value a business that utilizes digital solutions and offers immediate communication. While they are excited about job opportunities, they can quickly lose interest and burnout in a position that lacks challenges and growth. These qualities are often attributed to the generation's need for immediate gratification." [43]

Community colleges cannot attract the next-generation worker by offering lifelong job security in repetitive traditional trades. The nature of the work and opportunities to change and explore new things must be developed, emphasized, and marketed to replace the traditional, stereotypical view of the machinist trades if they are to attract the next generation of workers in sufficient quantities to meet Industry 4.0 market needs.

Issues driving the skills gap were challenging enough, without being exasperated by a global pandemic. The effects have been profound and cannot be ignored.

The Nature of the Challenge: The Skills Gap is Widening

The skills gap is widening due to disruptive events (Coronavirus pandemic)

The impact of COVID-19 on colleges and education has been devastating. All universities had to go to the online mode overnight and the plight of classes for the Fall 2020 semester is very uncertain. Most colleges are planning to reopen with the majority of classes offered in online format. Enrollment numbers are down significantly as many students are taking the wait-and-see approach and there is a strong sense of soul searching about the value of college education. In-person instruction, with its high price tag, is being replaced by online instruction. Naturally, the customer is doing a cost-benefit analysis and tending to pause and even deciding to wait out the pandemic. This is affecting the bottom line in all places of education.

James Krouse [44] of SAP discusses the changes in the college experience since COVID-19. Krouse states that universities are extremely unprepared to face the challenges created by COVID-19. However, "nothing breeds creativity like necessity." Krause states that in order to overcome challenges, higher education must evolve and adapt. "Educators must be willing to return to campus as well as be prepared and willing to teach online, partially or completely." Krouse discusses the expense of college, and how students might be hesitant to take out loans to pay for a "lesser experience." While universities address this, Krouse believes that the rate of failure in institutions on the edge will accelerate. Krouse ends his treatise by discussing the following three challenges: 1) Proctor tests in a fair and accurate way that prevents cheating, maintains necessary privacy standards, and is intuitive for students and professors; 2) Provide a space and access for programs requiring lab work and hands-on experience; and 3) Create an experience that begins to compare to the traditional college experience [44].

The future of many smaller programs is in jeopardy. "The ugly truth is many college presidents believe they have no choice. College is an expensive operation with a relatively inflexible cost structure. Tenure and union contracts render the largest cost (faculty and administrator salaries) near immovable objects. The average salary of a full professor (before benefits and admin support costs) is $104,820, though some make much more, and roughly 50% of full-time faculty have tenure. While some universities enjoy revenue streams from technology transfer, hospitals, returns on multi-billion-dollar endowments, and public funding, the bulk of colleges have become tuition dependent. If students don't return in the fall, many colleges will have to take drastic action that could have serious long-term impacts on their ability to fulfill their missions. That gruesome calculus has resulted in a tsunami of denial." [45] International students have been a valuable stopgap to fill the technical positions unoccupied by domestic students as well as the mainstay of engineering graduate programs. COVID-19 has disrupted that pipeline as well. Along with that, very difficult and confusing immigration rules make things more and more challenging for international students to come to the U.S. for advanced studies and then seek employment.

COVID-19 is not the only disruptive event, but it is one in a combination of multiple disruptions with cumulative effects on the skills gap. Many of the disruptions have the dual impact of increasing the speed and need for introducing technology, while simultaneously discouraging more students to select STEM careers.


Practical
Vision

The Nature of the Challenge: The Skills Gap is a Multidimensional Challenge for 2-Year and 4-Year Educators

The previous sections provided data and insight to identify the overall problems plaguing the Industry 4.0 talent pipeline. The following sections focus on specific challenges related to the academic ecosystem as it pertains to the disciplines of mechanical engineering, mechanical technology, and manufacturing. The physical disciplines are critical to Industry 4.0, as the composition and behavior of products and processes depend on the intersection of the physical and digital. The nature of the challenges will be introduced first, then areas of opportunity and specific suggestions will be provided.

Figure 6 illustrates the structure of the sections that follow. The academic ecosystem will be represented holistically, as a process. The secondary education curriculum is positioned in the middle of the figure, with inputs coming from the "supply side" and outputs represented by the "demand side." The overall process is designed to add value to its subjects, who of course are the students, engineers, and technicians that enter, learn, and finally matriculate through the process.

Figure 6 also includes a parallel block labeled "System-level." This block is in recognition of the fact that no system stands alone, rather it is part of a system of systems. The following sections will discuss how each of these blocks include unique challenges as Industry 4.0 disrupts the mechanical talent pipeline.

FIGURE 6: **Structure of the Academic Ecosystem**

Supply-Side: Investing in future workers
Efforts aimed at increasing the quantity of potential future workers that are aware of and interested in careers in mechanical engineering and/or skilled trades.

⟷

Integrating employer needs to educate qualified workers
Efforts aimed at delivering curricula and programs that effectively and efficiently produces sufficient qualified workers to fill industry needs.

⟷

Demand-Side: Delivering human capital
Efforts aimed at supporting the future workers as they enter the workforce and as they become lifelong learners and practitioners of state-of-the-art technology.

System-Level: Improving the overall ecosystem
Efforts such as policy and new cross-sector collaboration models that shape how the workforce and employment system operate.

The Nature of the Challenge: The Skills Gap is a Multidimensional Challenge for 2-Year and 4-Year Educators

Supply side challenge: Efforts to recruit future workers are scattered, unfocused and inefficient.

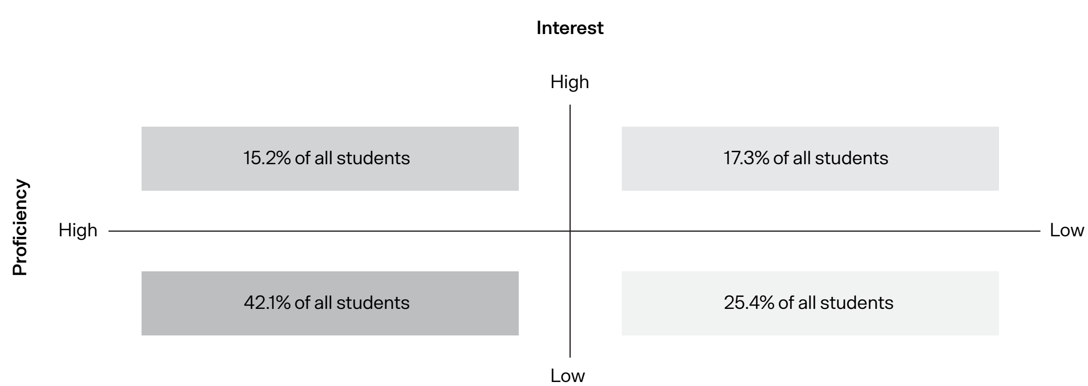
There are many well-known pre-college programs that are designed to build interest in STEM careers. The question is, do these programs create new interest? Do they bring in students that would not have chosen STEM otherwise? Or do they attract mostly those predisposed to STEM careers, such as the case of a child with a parent in a STEM field? To that point, in multiple interviews with engineering faculty, the topic of the FIRST Robotics program was discussed. Several faculty members described working with student teams that were composed of stereotypical students. There were no instances of surprising or unexpected participants, and not one case of a student participating to see what STEM is all about. It has been the authors' experience that many FIRST Robotics students do not make it all the way to engineering degrees. Often, these students get shocked when they are judged by their GPA and standardized test scores for college admission and financial aid, without regard for their FIRST Robotics activities.

These FIRST Robotics observations point to the issues of interest vs proficiency. A 2010 study by Business Higher Education Forum [46] shows that interest in a STEM career is one thing, while STEM proficiency in high school is another. The two are independent variables/quantities. Having one does not necessarily guarantee the other.

"Both interest in a STEM career and proficiency in STEM subjects, especially mathematics, are necessary prerequisites for students to select and succeed in a STEM major. But research by ACT indicates that fewer than one in five 12th graders have both high interest in STEM and high proficiency in mathematics—precursors to success in STEM undergraduate programs." [46]

Figure 7 shows the distribution of interest and proficiency. The pool of 12th graders who demonstrate high proficiency in math but low interest in STEM is more than one-quarter of all 12th graders. This would appear to be a significant opportunity to grow the pool of students who choose and succeed in STEM majors. Based on faculty interviews, and the authors' personal experiences, the students in the high interest, low proficiency category are also high potential future engineers. This group adds another 15% to the pool of potential high schoolers.

FIGURE 7: **Distribution of STEM Interest and Mathematics Proficiency Among 12th Graders [46].**



The Nature of the Challenge: The Skills Gap is a Multidimensional Challenge for 2-Year and 4-Year Educators

Figure 7: Distribution of STEM Interest and Mathematics Proficiency among 12th Graders Meanwhile, as we learn about the makeup of the high school ranks, generational transition is changing the motivational forces for young people. Young people are taking a very pragmatic view of higher education; a Harris Poll finding that shows the biggest enrollment motivator among 14 to 23-year-olds is financial security. Rather than pursuing individual passions or interests, students are selecting majors based on available employment [47]. This suggests the key to attracting young people has to include both personal interests and pragmatic considerations.

In addition to recruiting issues, retention of students plays a role in the supply side issue. In many cases, if academia does land a STEM recruit, there is a high probability that the recruit will not make it through the "weed-out" process. The incoming President of the American Society of Engineering Education (ASEE), Dr. Sorby, addressed and sternly discouraged the process of weeding out students. Dr. Sorby specifically called for education reform and further emphasized the importance of social justice and fairness (no longer weeding out) as a motivation for change [48].

Retention was addressed by Geisinger et.al [49]: "Some engineering students leave because they discover a passion for a discipline other than engineering—it is hard to argue that we should be trying to prevent such students from leaving. However, it is also true that a significant proportion of engineering students leave because the engineering educational system has failed to show them that the engineering endeavor is profoundly human, has failed to make relevant the key scientific, mathematical, and engineering principles needed for mastery of engineering, has failed to show that engineering is within reach of their abilities, has failed to capture their imagination and fascination, and has failed to provide a welcoming atmosphere to them." [49]

Their studies identified a common set of factors that play a role in students' decisions to leave engineering majors:

1) The culture in engineering programs tends to be individualistic and often involves very traditional types of teaching and advising
2) students may have difficulties understanding course material and competitive grading structures leave students feeling discouraged
3) students may lack self-efficacy or self-confidence
4) students may not have obtained adequate high school preparation
5) course material may fail to capture student interest
6) students may encounter additional obstacles due to gender, race, or ethnicity [49]

Researchers at Morehead State University [50] developed a summative poster that illustrates the many factors affecting recruiting and retention. They summarized their findings:

"*Interest in Q-STEM [Quantitative Science Technology Engineering and Math] among high school graduates was associated with passion for the discipline, teacher encouragement, and success in academic coursework. Upon entering college, students faced more difficult courses, higher-level mathematics, and college faculty who were perceived as less supportive and who emphasized passive teaching strategies. As a result, students felt inadequate, unprepared, and overwhelmed. A naïve understanding of study habits, the expectations of Q-STEM preparation, and test-taking strategies may have worsened the students' negative experiences.*" [50]

Perhaps the most poignant way of understanding the retention issue is to consider these actual quotes from former students in Table 10 below:

The Nature of the Challenge: The Skills Gap is a Multidimensional Challenge for 2-Year and 4-Year Educators

TABLE 10: **Assessing Why Students Leave Engineering**

Reason for leaving	Student
I wanted a job dealing with and helping people.	African-American Female
Part of the reason I left engineering was because I was being trained to be a machine with no thoughts or ideas of my own. I felt I was being very limited.	Latina
The biggest factor was that I didn't feel that being an engineer allowed me to fit in my artistic and creative abilities. I also felt that I was very different from other engineers. I felt that I got negative reactions from them because I went to parties and participated in other activities. Even though my grades were usually higher, people didn't usually think of me as being as smart as they were.	Caucasian Male
I did not want to be working in a cubicle for the rest of my life, no matter how much it pays.	Caucasian Female
The curriculum was extremely narrow… There was little to no room for any humanities or city planning or any other type of class. I feel that this is a MAJOR failing of the engineering program.	Caucasian Female
I was unhappy in the major and felt that no matter how hard I worked, I could not get good enough grades.	Caucasian Female
The fact that my grades were low and I was on the verge of being asked to leave my field of engineering.	Latina
The first semester workload was extremely heavy, especially for students coming straight out of high school.	African-American Female
I did not get any sort of orientation that helped me decide which engineering program to pursue. I was simply overwhelmed by which engineering major to choose, so I chose to join a different college.	Caucasian Female
I like math/science; what in the world would I do with an optical engineering degree? Would I like a job? I had no answer, so could not risk my future.	Latina
A stronger focus to what I would be doing afterward. Everyone I ever asked about what an engineer did had vague answers.	Caucasian Female

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The supply side challenges, including the retention issue, affect the number of students entering the education ecosystem. But the academy itself struggles to keep pace with Industry 4.0. The following section explores the challenges associated with Industry 4.0 driving rapid evolution in curriculum.

Educators challenge: Integrating employers' needs into curricula is met with internal and external resistance.

Academic institutions are currently running operations with a system resembling an assembly line, which resembles an Industry 2.0–type mentality. The academic systems are designed to efficiently process students through the school, like an automated assembly line. This is certainly efficient for making money for academia, but is it in the best interest of the student? The students don't think so. In a recent study by ASEE, Phase II: Insights from Tomorrow's Engineers Meeting Report 2017, it was discovered that:

"*Participating students concluded that their institutions were paying insufficient attention to multiple KSAs (Knowledge Skills and Abilities) needed to produce the desired T-shaped professional.*" [52] *[The term T-shaped means that a person has knowledge and skills in a wide range of topics (represented by the top of the "T") and that person has great depth in select topics (represented by the stem of the "T").]*

Students did not fault the subjects emphasized in their education (particularly the rigorous grounding in math, science, and engineering fundamentals that are a priority of engineering programs), but they criticized how these, and other, courses were taught [52]. Similar sentiments were expressed by students in attendance at a recent Industrial Engineering and Operations Management conference in Toronto, Canada (Fourth North American Conference on Industrial Engineering and Operations Management, Toronto, CA, October 25–28, 2019) [53]. The authors conducted workshops in which current students and recent graduates expressed concern that the academic system had not adequately prepared them for the workplace, due to outdated curriculum.

Students are keenly aware that the old-school method of only relying on chalk and whiteboard is simply inadequate for an Industry 4.0 world. Also, in the ASEE study, an oft-repeated demand was for mentoring, whether by older students, faculty, professionals in industry, or peers. "The best test of knowledge," one student said, "is to try to teach others."

Far beyond the scope of this paper, but mentioned here for the record, is that authors have often encountered students, administrators, and faculty who believe the time-honored promotion and tenure process should come under deep scrutiny. The claim is that tenure has become a means to resist change, to protect the status-quo, and to exclude unwanted ideas, the exact opposite of what it is intended to do. But tenure is not the only issue. The following quotes were extracted from the ASEE TUEE reports, citing issues that hamper academic reform:

"*Assessment poses a big challenge. ABET may need to be involved.*" *[ABET is the nonprofit, ISO 9001 certified organization that accredits college and university programs in applied and natural science, computing, engineering, and engineering technology.]*

"*Faculty will feel at a loss grading reflection, and a lack of clear expectations will cause students to fret.*"

"*Engineering faculty cannot control general education requirements.*"

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"Freshmen, it was noted, are ill-prepared for open-ended projects."

"Co-curricular activities detract from time devoted to academic activities—and how do you grade them?"

"When you ask me [faculty] to do more, I have to do less somewhere else . . . my class is too large . . . Why are we doing this; it's not our responsibility . . . there's no budget for it."

"The reason our colleagues don't do active learning is that they're scared of being in a student-centered environment where they might be asked questions they don't know the answer to." [52, 54–56]

Beyond the border of the United States, similar problems exist internationally with some variations influenced by local culture. For example, the majority of engineering students in India study a curriculum that is theoretical in nature and is quite similar to a curriculum that is many decades old. Only about 46% of all graduates from Indian colleges are considered to be employable [57]. About a decade ago, a McKinsey report concluded that only a quarter of engineering graduates in India were employable. A new study has made an even harsher conclusion that about 94% of Indian engineers are not employable [58–59]. While there can be a debate as to the actual number, there is no doubt that a problem exists.

A large number of Indian engineers graduate with a degree but with very few skills. The root cause of this goes back to a problem with curriculum, lack of enough quality teachers to meet the demand, and a pedagogy that lays heavy emphasis on acquiring enough information to pass examinations but no emphasis on developing skills. Many students, however, realize that skill development is important, so they are hungry for opportunities. They are interested in learning to use new technology and problem-solving tools.

A bit of anecdotal evidence can be shared here. One of the authors of this paper (Shuvra Das) taught two modeling and simulation-based hands-on classes at an Indian university in January 2020. Both were week-long classes and used Matlab and Simscape (a Matlab toolbox). The university had a full-fledged license for the software, but it was surprising to learn that the students had never used it and no faculty member was using it for any of their classes. During the week-long class, the students got an opportunity to learn to use the tools to solve meaningful engineering problems.

At the end of the course, the instructor suggested that the students form a simulation club. This suggestion was received with a lot of enthusiasm and excitement among the students. However, shortly after this, the COVID-19 pandemic led to the university's shutdown. Since then, many of the students who took the class have been taking Matlab training courses and earning certificates online as they are honing their skills. That week-long course put them on a path of self-directed learning and acquiring of skills. Students will grab these types of opportunities if they are offered. The problem is that no one is offering them the opportunity or providing the necessary tools to get started.

The digital transformations of Industry 4.0 are certainly crucial, but interviews with current educators in the mechanical disciplines have uncovered another challenge. Although Industry 4.0 is driving a digital mindset, and in some cases "vaporizing" everything physical, there is still no escaping the need for the physical element. Often lost in the enthusiasm for a digital curriculum is the fact that mechanical systems will always have a physical embodiment as well. The need for "hands-on" experience is still there and always will be. The educators emphasized that there can be no virtual replacement for the visceral experiences involved with fabrication, assembly, use,

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maintenance, and disposal. As Industry 4.0 presses the case for digital transformation, we must not abandon or neglect training in the laboratory, the workshop, and in the field [60–74].

The pace of change driven by Industry 4.0 within academia is staggering, but so are the demands on companies that will become the employers of academia's newly minted engineers and technicians. The following section describes challenges related to the interface between academia and industrial ecosystems.

Demand side challenge: The output of human capital lags behind industry's needs for capacity and competency.

As described in an earlier section of this report, the number of technology workers and the competencies needed by industry are changing faster than outdated degree programs can evolve to meet the demands. Meanwhile, corporate HR departments, often managed by non-technical staff, do not update their talent searches to look for non-traditionally degreed personnel (e.g., mechatronics). The evolution of the curriculum and the digitization of technical work has altered the skill mix on the resumes of recent graduates.

In recent conferences on industry-academia relations, the authors have received feedback from industry liaisons requesting the curriculum focus more on "employability skills," such as problem formulation and collaborative problem solving. These requestors suggest eliminating some traditional core materials to make room for soft skills. As technologies morph and evolve for employers, they look for technical workers who can evolve as well. The authors point out that the nature of next-generation workers actually aligns well with this need. The workers are looking for opportunities to experience new challenges, to develop new skills, and to try new technologies. The employers recognize the need for technical agility; next-generation workers want technical agility, but academia is resisting the change.

In some circumstances, STEM graduates and two-year students that are frustrated by the lack of academic progress will choose to avoid traditional corporate careers. They now have options such as joining a startup or launching their own venture. Freelance contracting and self-employment are now viable options. As employers eliminate traditional pensions, "early-retire" lifelong employees, and reduce long-term benefits, next-generation workers are becoming more independent, less loyal, and no longer count on employers for lifelong careers. The next-generation worker is prepared to change jobs and change employers as often as necessary. Academia must recognize this new normal and reconfigure curriculum to deliver what is needed and wanted by students and employers—otherwise, the market will look elsewhere for technical education.

System level challenge: The social ecosystem is dramatically widening the gap.

Society and students see value in portable credentials as a means to open doors for careers, but students are less and less constrained to traditional school for those credentials. Online, non-traditional programs have become acceptable equivalents, and in some cases superior. Online learning providers such as Coursera, Edx, Udacity, LinkedIn learning, and others are providing certificates and micro-credentials through high-quality curriculum offerings in areas that are modern and relevant to industry needs. While these are viewed as continuing education credits, many universities (such as many private universities in India) have started encouraging students to use these e-courses to substitute for the on-

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campus courses that are part of their degree programs. More importantly, many companies are starting to acknowledge these types of certifications and skills as legitimate demonstration of qualifications as they move away from strict adherence to college degrees. For example, Google has started to offer affordable online six-month certification programs in data analytics and project management. They will also accept these credentials for employment at Google, and students do not require a college degree to enroll [75].

COVID-19 has had a profound impact on our society, and the pandemic is not over (as of the date of this publication). Community colleges are re-assessing their roles in keeping costs down. This crisis is causing students to stay home, choosing local schools rather than entering dormitories on campus at four-year universities. And the U.S. perception and reception of international students has been altered by COVID-19. International student visas are being revoked as international travelers are considered potential global spreaders of the virus.

Areas of Opportunity: Closing the Skills Gap

The following sections will address the academic ecosystem as it pertains to mechanical engineering, engineering technology, and the associated acts of making sophisticated products. The nature of these challenges was introduced in the above sections. In the following sections, opportunities and specific suggestions are provided. Figure 8 is an illustrated summary, organized by ecosystem blocks.

FIGURE 8: **Illustration of the Opportunities in the Academic Ecosystem**

Supply-Side: Investing in future workers

1. Support PLAY: Preparatory Learning for Adults (upskilling) and Youths (pre-college)
2. Deliver PRIME narratives to: Promote, Retain, Inspire, Mentor, and Encourage workers

↔

Integrating employer needs to educate qualified workers

3. Align credentials with employer needs
4. Deliver curricula anticipating the near-future state of the art

↔

Demand-Side: Delivering human capital

5. Deliver workers that immediately add value to the employers
6. Deliver workers that are "ready to go Industry 4.0!"

System-Level: Improving the overall ecosystem

7. Address the "social determinates of work" 8. Promote cross-sector collaboration

Supply side opportunities: Increase and optimize efforts to recruit future workers, both domestic and international

Opportunity 1:
Support Play/Active Learning for Adults and Youth. (PLAY)

The next generation of workers is growing up as digital natives. The digital impact is already appearing in the workplace. In a study by the accounting firm Sikich, it was reported that Millennials value a workplace where digital solutions are utilized and immediate communication is offered. Millennials are quick to lose interest, usually attributed to their need for instant gratification [43]. Mckinsey suggests there is a need to redesign the workplace based on the conclusion that "automation and the proliferation of technology are reducing the need for human intervention in many basic, routine tasks, the very activities entry-level professionals used to focus on." [28] The digital native worker represents the new norm.

Digital capital is the means to get the attention of the digital native. Bongomin, et al. 2020 [76] states: "We have entered a nascent paradigm shift (Industry 4.0) where science fictions have become science facts, and technology fusion is the main driver. Thus, ensuring that any advancement in technology reach and benefit all is the ideal opportunity for everyone." Children are growing up surrounded by technology their parents could not have imagined. The reach of Industry 4.0 technology is extensive and growing each day. Technology is driving change in education, with digital natives in the academic ecosystem. Several trends are emerging and beginning to be branded as "Education 4.0."

Peter Fisk [77] claims there are nine trends related to Education 4.0:

1. Learning can take place anytime, anywhere.
2. Learning will be personalized to individual students, by individual students.
3. Students will have a choice in determining how they want to learn.
4. Students will be exposed to more project-based learning.
5. Students will be exposed to hands-on learning (internships, mentoring, projects).
6. Students will be exposed to data interpretation to learn to make inferences.
7. Students will be assessed differently.
8. Students' opinions will be considered in designing the curriculum.
9. Students will become more independent in their own learning.

The nine trends of Education 4.0 will shift the major learning responsibilities from instructors as the prime knowledge delivery mechanisms to students as owners of their own education, self-pacing as lifelong learners. Instructors still play important roles to support learners, but must realize that education is not for the benefit of the instructor, it is for the learner. Instructors should never consider conventional teaching as the only or "best" path.

The nature of K–8 education is also being challenged. Traditional classroom rules such as "raise your hand to speak" and "stay in your seat" are being questioned. Ana Lorena Fabrega calls herself an EDUpreneur. She is the co-creator and facilitator of ART SENSORY PLAY, which is a "messy, fun, and developmentally appropriate activity for toddlers to explore the world around them using all their senses" [78]. She is an advocate and social media influencer on the topic of K-8 education.

Recently, Ana Lorena Fabrega suggested new guidelines for K-8 [79]:

1. Shareability – Kids share their creative imagination with others
2. Culture of Collaboration – Kids talk to friends about ideas
3. Seeds of Creation – School sets the culture for kids to build and create
4. Building Lectures – Kids learn by doing
5. Give up Power to Empower – "Controlling" kids ends up preventing learning
6. Rapid Prototyping and Fast Feedback – Encourages kids to iterate
7. Ambitious Goals – Kids have more potential than we give them credit for
8. Accountability – Grades don't work, checkpoints do
9. Graduation – Not an end, but a beginning in real-world learning
10. Encourage Experiments – Learning by doing

The role of play/active learning dominates her list for children, but this is not the only academic level where the importance of adding play/active learning is emerging. During the American Society of Engineering Education's 2020 annual conference, the keynote speaker reinforced the need to make room in academic programs for such things. He gave this reply when asked, "What

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do we cut from the [crowded] curricula to make room for this new style of learning?"

"There is a lot of stuff [engineering topics] that has to be learned, but you have to ask yourself, 'Do you also have to teach it?'"
Aldert Kamp, TU Delft [80]

In his keynote address, Dr. Kamp outlines a new model for engineering education, in which he emphasizes the importance of "long-term thinking" and "front-end innovators." It is clear that the skills he proposes do not lend themselves to traditional classroom lectures. Terms like agility, entrepreneurial, holistic, interdisciplinary, and creativity appear often in his address. It is important to note the significance of ASEE choosing this type of keynote for an ASEE annual conference. It is a sign of change in engineering education.

It is clear that experts are advocating for much more experiential-type play and active learning in place of the current over-dependence on traditional lecturer/listener classroom formats. And the calls to change are on all levels of education. Aziz Hussin [37] published a list of nine fundamental digital skills needed by instructors, and he lists many tools available for instructor use (See Table 11). The list includes many tools for the creation of game-play education.

TABLE 11: **Nine Fundamental Digital Skills for Instructors Source**

Digital skills	Tools		
Record and edit audio clips	SoundCloud, Audioboom	Vocaroo, Clyp	
Create annotated, interactive, and engaging video content	Blubbr, Magisto, TeachEm	TED-Ed, Edpuzzle, WeVideo	
Create visually engaging content	Piktochart, Canva	Glogster, ThingLink	Google Drawings
Use social networking websites to create PLNs, connect, discover new content, and grow professionally	Twitter, Facebook	Google Plus, LinkedIn	
Use blogs and wikis to create participatory spaces for students	Blogger, WordPress	Kidblog, Wikispaces	Edublogs, Weebly
Use social bookmarking websites to curate and share resources with your class	Diigo, Scoop.it	edshelf, eduClipper	Pinterest, Symbaloo
Create engaging presentations	Prezi, Haiku Deck	Google Slides, Zoho Show	
Create digital portfolios	SeeSaw, Pathbrite	Silk, Weebly	Google Sites
Create non-traditional quizzes	Testmoz, Quizalize	Riddle, QuizBean	Flipquiz

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The movement to play/active learning is an opportunity for technology providers to significantly impact Industry 4.0 talent supply. By introducing technology topics in kid-friendly (and fun) ways, Industry 4.0 technologies can be introduced, become well known, and perhaps even become common sense to the point of children asking, “Why would we do it any other way?” Play/active learning becomes the only engineering outreach tool when a young person has no other connection, association, or means of becoming aware of technical career opportunities.

The effectiveness of play/active learning is well documented, but the inclusion of gamification lags behind the need for it. Fernando Almeida and Jorge Simoes [81] studied the role of games, technology, and Industry 4.0 in transforming higher education, or Education 4.0. They used 25 case studies in their research. Gamification was present in less than 20% of the projects. They found that the main benefits to education by gamification was a “greater involvement of students in projects, development of their skills, and application in a real context.” They found that the main difficulties were “the simplification of the real world made by these applications, the difficulties inherent to their inclusion in the didactical system, and the limited capacities to offer greater interactivity without predefined external stimuli.” [81]

The technologies of Industry 4.0 can be utilized to create needed tools. A few potential examples are provided below to illustrate the possibilities. With effective simulation and visualization “games,” future skilled trades workers can learn trades with far less physical machine time. Mentors can provide instruction and training with game-like challenges. For example, young people could be given virtual fabrication challenges. Each challenge adds a new aspect of fabrication and a new skill. This type of training can incorporate health and safety training in a dramatic but natural way, without risk of injury.

ASEE recognizes that industry and tech suppliers are key partners in the development of curricula. ASEE’s TUEE report suggested “new areas of activity would be defined, with corporate members engaged to support cross-society initiatives.” Other industry partners pledged to help establish an education track at a society’s national convention, incorporating both computational thinking and systems engineering in a Body of Knowledge [56].

The effort does not have to be limited to domestic companies. Through cloud computing and 5G data transmission, development teams can become international. Language and distance barriers can be overcome to add international experiences. Economic and social differences may be major barriers, but crossing the chasm digitally holds the promise to bring international collaborators together.

Universities and students outside the U.S., especially in the Eastern world, are hungry for this kind of connection. For example, in India the engineering student pool is huge and the educational institutions are many. All of them are constantly seeking some form of partnership with educational institutions from the U.S. Developing the logistics of cooperation for joint projects, formation of project teams, and offering courses to be co-taught by several institutions are easily possible. Companies that have an international presence can also play a significantly meaningful three-way partnership role in such an endeavor. The personal learning goals of students, the goals of the company, and the goals of the universities can be very well aligned in such a partnership. An international team of students directed by mentors from an international company and coached by faculty from partner institutions offers a rich experience for the learner.

Summary of opportunity 1: Provide the means for educators to introduce technical topics through play/active learning. Start early (K–8) and don’t be constrained by your perception of the traditional classroom you grew up in.

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Opportunity 2:
Deliver effective narratives – Promote, Retain, Inspire, Mentor, and Encourage future workers. (PRIME)

From April to July 2020, the authors interviewed a cross section of university faculty and administrators from a variety of two- and four-year engineering and engineering technology programs to get a sense of current thinking around what educators are doing well, not so well, and what needs to be done to improve. Table 12 provides an overview of the themes that emerged from the interviews.

TABLE 12: Insights and Themes from Engineering and Computer Science Faculty*

What are 3-5 things that engineering educators are currently doing very well to address the development of an Industry 4.0 workforce?

1. Integrating hands-on "making activities" with digital tools, coding, and design
2. Project-based learning being implemented across all four years of undergraduate studies
3. Incorporating entrepreneurial thinking and employability skill development into curricular and extracurricular activities
4. Bringing in design thinking concepts including opportunity identification and generative design methods
5. Introducing new software (Python for example) and coding activities into curriculum

What are 3-5 things that engineering educators are not doing very well to address the development of an Industry 4.0 workforce?

1. Understanding how to properly integrate and blend making things in both physical and digital domains
2. The need to bring "robotarian cloud-based" test beds and platforms to robotics
3. Understanding how to combine new industry 4.0 technologies into curriculum in economic ways
4. Not onboarding and properly preparing students to effectively enter industry and be work-ready
5. Accepting that curriculum and methods need significant reform and failing to act on these needs collectively and collaboratively

What are 3-5 things that you advocate should be changed to accelerate engineering education reform to address the development of an Industry 4.0 workforce?

1. Improve collaboration with industry including reform of cooperative education and faculty development
2. Increasing cross- and trans-disciplinary collaboration and integration of mechanical, electrical, and industrial engineering and computer science
3. Borrow from and incorporate concepts from medical schools (like teaching hospitals) to establish "teaching factories"
4. Improve the education of parents and prospective students as to how engineering and manufacturing in particular are changing and why there are career opportunities
5. Developing, improving, and calibrating a new set of dynamics and applications to integrate the physical, digital, and human domains into the educational experience

**In-depth interviews were conducted by Pistrui and Kleinke during April-July 2020. Faculty and administrators from a cross-section of four- and two-year, public and private educational institutions participated: n=15 [60-74].*

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*In depth interviews were conducted by Pistrui and Kleinke during April-July 2020. Faculty and administrators from a cross section of four- and two-year public and private educational institutions participated: n=15 [60-74].

Although this sample is small, these insights parallel the findings of previous research, including Pistrui et al. 2018; 2019; 2020, the work of Das et al. 2020 [4–7].

Opportunity 2 is about becoming purposeful, intentional, and aggressive about the image of the engineering profession by creating and disseminating narratives that inspire, while fighting against stereotypes that discourage.

What image comes to your mind when you picture an engineer? Is it a picture of a 1960s vintage NASA control room, full of crew cuts and horn-rimmed glasses? Does the socially awkward geek on the popular sitcom come to mind? Or do you see an Einstein image with wild hair and equations on a chalkboard? These are the images and narratives commonly used to represent the engineering profession.

We can quickly see what young people find when they do an internet search for images of engineers. Try it. You will likely get many photos of people in hard hats at construction sites, dressed in either suits or white lab coats. Most photos show the "engineer" holding a paper drawing, or with a scroll under their arm about to compare the site to the drawing. But isn't this outdated? Who makes paper drawings on scrolls anymore? This is the internet's image of our profession. Mary Barra's picture does not pop up. Neither does Elon Musk or Bill Gates. No 3D CAD, no digital factory, no virtual reality, no 3D printers, not even a tablet or a laptop in most images. This is the non-engineer's image of our profession. And it is not as if the images of the items mentioned (computers, digital factory, etc.) are missing from the internet; there are plenty of images of those elsewhere online. However, the connection is missing. The message that engineers work with and work on all this cool stuff is missing. People today are huge consumers of technology in their daily lives and have a good sense of the meaning of the word "technology," but they are largely unable to connect technology to engineering or engineers.

Question: This is a graphic showing common professions. Can you find the engineer?

FIGURE 9: **Can You Find the Engineer? What Value Does This Bring?**

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We have to ask what image we wish to project, rather than allowing ourselves to be branded by those outside the profession. And, if we think the standard hard hat image (or worse, no image at all) is the way to go, we have to ask whether young people and their influencers view the hard hat as a positive narrative, something they would aspire to or encourage others to do? Seems unlikely. Effective narratives are needed to tell the story of Industry 4.0.

Big Data sorting and parsing of key performance indicators can be used to promote technical careers by tracking movement in the motivations and interests of generations. Then, aligned with those motivations, focused narratives promoting technical career paths can be presented to show young people their potential. The TTI data referenced earlier in this report can help us identify what personality type a certain student is and the message to appeal to their senses can be dynamically altered. A big-picture thinker may find the message of solving one of the grand challenges more appealing, while a tinkerer may find a message about a particular feature of a robot more appealing.

The TTI data that focuses on motivations for NGEs and NGSTs suggests that both of these groups would be receptive to input into their decision-making processes (see pages 23–25 of this report). TTI data can be used to identify those most likely to be a fit for certain types of technical jobs, as well as identifying those who are most likely to be content in such positions.

Retention of talent already in the pipeline needs to become a priority. Tools like IoT can be used to help students succeed and alert educators to problems before they become problems. For example, study habits and self-discipline can be measured with IoT embedded in items students use during their academic work, be it physical objects such as calculators or virtual ones such as communication tools, software, or learning management tools.

Hypothesis: A “triage” heuristic, similar to a hospital emergency ward, will help efficiently use recruiting resources. Triage 1) Don’t spend money on those you’ve already won (let those who will recover on their own, recover on their own); 2) Don’t spend money on those you’ve already lost (let the dying die); 3) Spend money on those who need to be swayed (give priority to the patients where your intervention will make a difference).

As described in the publication *Increasing the Number of STEM Graduates: Insights from the U.S. STEM Education & Modeling Project by the Business Higher Education Forum*, [46] motivation and preparedness are independent of each other. Students who are motivated and prepared may not need any intervention. Those who are prepared but not motivated will need a motivation intervention. However, those who are motivated but not prepared will need intervention with academic material to become better prepared for success.

Inspiration can come from many places. For example, a simple and affordable 3D printer can capture the interest of a young person. Robotic toys with embedded easily programmable controllers can be an introduction for the future mechatronics engineer. Also, all young people are not inspired by the same thing. For example, a fight between sumo-bots may be something that one group is excited about, while cleaning up a local pond of pollutants may be a source of inspiration for someone else. Young people need to get the right tools in their hands so that they can learn how to act on their inspiration. The earlier they start, the more inclined they will be to gravitate toward the profession.

Mentors can be made available to struggling students. There are opportunities to better utilize international students and workers. For example, while in parts of the U.S. the number of college-age students interested in engineering shrinks, there is no dearth in student numbers in other parts of the world, such as in India and China. In India, medicine and engineering are the two most sought after college degrees among youth and their families. This demand is supported through educating students in state institutions, as well as many private universities across the country. The marketplace is high-supply, high-demand, with motivated students seeking a degree.

However, work needs to be done on improving the quality of instructors and modernization of curriculum. Many employers view a large percentage of graduates as unemployable. The curriculum is heavy on theory and content that is dated, but light on applications. Students do not get a lot of opportunity to experience working on real problems, even though they are eager to get that experience. And the number of qualified and trained teachers available in the country is not close to being enough to meet the high demand. Mediocre and poor teachers lack the imagination and confidence to motivate a population hungry to improve their skills.

This situation in India offers several opportunities. Students who are employable should receive more opportunities to improve their skills. This group can also form the pipeline to support (either remotely or through immigration) needs of industry in the West. Students who are motivated but are stuck in classrooms or curriculums that fail to inspire and train may be helped through curriculum reform and system reform. This process should include innovative decentralization of curriculum standards as well as flexibility of instructor hiring process, both of which are currently rigidly controlled by government entities. Plaksha University (www.plaksha.org) is a new private university that was started by 80 highly successful entrepreneurs in India with the goal of training and graduating engineers that their companies would be eager to hire. The curriculum is integrated and modern, traditional silos of engineering are broken down, and the pedagogy integrates theory, application, mentorship, and hands-on projects, achieved through intimate integration of learning and doing. They are hiring educational reformists and experts from around the world to join in this effort, as advisors as well as active participants.

Lifelong learners thrive when encouragement is provided. Two-year college programs are easily accessible and are very affordable. An example of purposeful and determined encouragement can be found in the National Science Foundation's (NSF) Advancing Technological Education (ATE) program #1744627 [83]. This grant provides a new Curriculum Dissemination Service to help develop and deploy documentation and mechanisms to help ATE projects and centers. With the grant, NSF shows they are interested in improving collaboration and cooperation among educators, which in turn benefits the lifelong learner.

Summary of opportunity 2: Providing effective narratives, in a purposeful and intentional way, can encourage young people to consider the engineering profession and to remain in it once chosen.

Educator's opportunities: Rapidly integrate employer's needs into the curricula used to educate qualified workers.

Opportunity 3:
Utilize academic/technology provider partnerships to create curricula that are relevant, attention grabbing, and critically assessed by real-world standards.

Academic/technology provider partnerships can benefit from including a sociological component in their development process. With five generations in the workforce, each with its own unique characteristics and attributes, understanding how people interact with technology will help instructional designers strengthen and improve pedagogical techniques and partnerships. By integrating data-driven tools like the TTI TriMetrix DNA assessment suite, it is possible to create curricula that resonates with learners and can be aligned with real-world scenarios.

Below are some responses to the question in the ASEE TUEE report: "How might academe provide instruction and tailor learning appropriate to deep preparation for industrial employment experiences and internships/co-op/etc?"

- "Have better integration and consistent and strategic collaborations with industry (more than guest speakers, faculty with experience from years ago, and internships). Somehow, we need input from industry."

- "Academe should adapt its model of learning to provide experiences that more closely align with industry practice, facilitate lifelong learning, and move beyond the book problem solving approach found in most academic models. One approach would be to more purposefully integrate the educational and internship/cooperative experiences. Such an approach would include much more project-based learning experiences earlier in the educational experience. Students need more frequent experiences that incorporate project management skills, professional skills, and their technical knowledge."

- "Include lab courses that focus on different aspects of industry, including maintenance of equipment, learning different types of equipment, reading P&IDs, process safety management, etc."

- "Establish centers on campuses focused on (especially during summers) the workplace." [54]

In several programs around the world, creative approaches have been taken to integrate the curriculum with the needs of the profession. Four examples are quoted in the research paper [4]. These are: Singapore University of Design and Technology, City College of London, Technical University of Delft, and the Charles Strut University in Australia. The strategies used include: breaking down traditional engineering disciplinary barriers and creating new focal areas more in alignment with today's technological world; flipping the curriculum so that students learn much of the traditional theory online and spend in-person time on hands-on learning at the workplace, integrating practical applications with theory/concepts in a just-in-time format, etc.

Another example worth mentioning is Olin College, where a new, unique engineering curriculum was established from scratch that is quite different from traditional programs. Like at Plaksha University, emphasis is placed on the integration of real-world engineering with the curriculum, and real-world problem solving and skill development are valued over knowledge accumulation and testing.

The measure of success in the U.S. does not necessarily translate to success on an international scale. For example, a student or a company in India will have different aspirations and goals than their counterparts in the U.S. Shared benchmark data, coordinated experiments, and focused research can be used to optimize programs on a regional basis.

Engineering curricula and training can be divided by job description rather than by traditional disciplines (e.g., mechanical/civil/electrical). As Dr. Kamp pointed out in his keynote, the main needs are in research engineering, system integration, and interface/user experience engineering. The training and personality/mindset needed for these jobs are different from traditional engineering disciplines. TTI data can be used to differentiate talents for these focal areas, and the curriculum and marketing message to appeal to each group will also need to be tailored. For example, a student who has a big picture/broad goal mindset might be swayed by the societal impact of engineering and might benefit from a different curriculum from someone who is a habitual tinkerer and finds joy in fixing computers.

Hypothesis: Technology providers can be better utilized by academia. The aforementioned Google programs in data analytics and project management are a good example [75].

Summary of opportunity 3: Engage in the creation of curricula that delivers advanced technology to the classroom in near real time and in a manner that represents industry practices.

Opportunity 4:
Provide portable credentials (two- and four-year) that align with employers' Industry 4.0 needs, but are also affordable and accessible for lifelong learners/workers.

Students are attracted to academia as they seek to improve their personal value in the marketplace for technical professionals. Academia provides value through the promise of transferable credentials that enable workers to command higher salaries. Employers depend on academia to award diplomas based on reliable assessment of earning. Traditionally, employers have not questioned the veracity of the degree. Employers have set salary offers based on the prestige of degree-granting institutions. But this system has been coming under fire as academia struggles to keep pace with Industry 4.0. COVID-19 has forced academia to convert to online classes, which has given employers further reason to reconsider the academic value proposition.

New approaches to badging such as stackable credentials and non-traditional degrees have emerged. New companies have emerged to specialize in credentialing and certification. New thinking in academia has led to criticism of traditional accrediting practices, such as the Accrediting Board for Engineering and Technology (ABET). The authors' interviews with current faculty reveal that the digital disruption of Industry 4.0 is reshaping the traditional definition of the mechanical engineer and the mechanical trades. Credentials need to be agile and flexible to keep pace with Industry 4.0.

Restructuring of curriculum must be accompanied by a restructuring of credentialing. An example of this type of work is found in the biotech profession. The Los Angeles Mission College's program for biotech is sponsored by the National Science Foundation's ATE grant. An interesting marketing communication from the program is shown below. (See Figure 10.) This curriculum is another example of how programs are adopting education 4.0 structures. But along with the new program, note the emphasis on "stackable" credentials that "prepare students to enter the workforce in a short period of time" [84].

FIGURE 10: **Example of a Biotech Program Description Including New Credentialing Source:** [85]

Featured Project

Increasing the Student Biotech Pipeline

http://www.lamission.edu/Allied-Health/Biotechnology-Certificate/Home.aspx

Los Angeles Mission College (LAMC) will prepare community college and high school students for jobs in biotechnology. The new programs developed will explicitly address skill development and offer students counseling, tutoring, industry field trips, external speakers, and internship opportunities. Combined with excellent instruction in the classroom, these activities will prepare students for entry-level, middle-skill technician positions. LAMC serves a large underrepresented student body and will provide these students with employment opportunities in a high growth sector that needs a skilled workforce. Project evaluation will focus on measuring student progression, success, retention, and degree attainment.

LAMC will develop new academic pathways and curricula in biotechnology leading to stackable certificates and an Associate of Science degree. Stackable credentials will prepare students to enter the workforce in a short period of time while retaining the opportunity to pursue higher degrees at a later date. It will also allow for flexibility that will contribute to student retention and success. The project will provide high school students an opportunity to earn college credit and credentials that will ultimately assist them in obtaining employment.

As the digital era moves forward, the application of machine learning (ML) and artificial intelligence (AI) will alter the course of study in ways that can be tailored to the needs of individual students, rather than force-fitting individuals to conform to the masses. This means that competency testing and credentialing must change, as the one-size-fits-all mentality is no longer suitable. Independent credentials can also be used to qualify international students, especially those with degrees from lesser-known schools.

Finally, rather than depending on academic institutions to self-assess, a better approach might be to award credentials based on third-party assessments and competency tests. Professional societies have served this purpose in the past and can be very effective (perhaps more) outside the academic system.

Summary of opportunity 4: Provide the platform by which workers can build their dossier of skills and credentials. The dossier must be fully vetted, sanctioned, and transferable.

Demand-side opportunities: Investing in future workers, domestic and international

Opportunity 5:
Deliver workers (from two- and four-year institutions) who immediately add value to their employers.

Time required for onboarding can be shortened by developing processes and/or tools to give new hires the opportunity for either real or virtual experiences.

In many instances, the community college student is actively employed while pursuing a new skill or a two-year degree. Their technical education is provided by the college, but learning can occur in the context of an actual job. While this provides the real-world context, the application of Industry 4.0 technology could be used to replicate their environments with a digital twin. The virtual world can then be used to simulate unconventional situations or to rapidly demonstrate problem solving in a safe and efficient way.

With AI and ML, students can quickly search and find answers to problems that are already solved. College curricula should no longer grind through tedious scripts, formulas, or memorizations. The education systems must turn the emphasis to "learning to learn," problem-formulation skills and disciplined problem solving. As described earlier in this report, generational transition must be accounted for. Carutasu points out "The Fourth Industrial Revolution (Industry 4.0) imposes a rapid evolution (or revolution) of the human resources paradigm in engineering: Millennials should adapt to that paradigm, and the paradigm should be adapted to them." [86]

Corporate learning and development departments are typically run by non-technical people, so they struggle to understand the technology needs in the company, to communicate needs to academia, and to keep up. Reformed HR departments can team up with professional educators to create curricula that are relevant to the company's needs. With badging and credentialing, training programs can deliver transferable credentials to employees, making training more attractive as they onboard. Unfortunately, traditional HR departments are not skilled in rigorous education or academic pedagogy. To facilitate the rapid integration of new technologies, a new position academic/industry liaison arrangement is needed. The liaison could be employed by the academic institution or by the industry partner. Technology providers could support the liaison work by identifying gaps, running analytics on software use, or provide data to support decision making. New methods in assessment are being developed to assess employment skills (known as "soft" skills) [87].

In addition, technology providers could be contracted by HR departments to help look for technical people who are regular users of Industry 4.0 tools, rather than evaluating them based on school prestige or traditional degrees. In the future, HR departments could find people who are well suited and great fits for open positions, but who don't happen to be affiliated with a college. This could reduce the onboarding time for new employees.

Summary of opportunity 5: The exponential growth of Industry 4.0 technology has created an opportunity for the ecosystem to deliver entry-level workers armed with cutting-edge technologies, which in turn will have an immediate impact on corporate bottom line.

The Nature of the Challenge: The Skills Gap is Widening

Opportunity 6:
Deliver workers (from two- and four-year institutions) who are qualified in advanced digital technologies.

Agile and responsive academic institutions are keeping up with technology. Those that are not are facing bankruptcy and irrelevance. The need from the industry side is captured by an article from Bonnaud & Bsiesy [88]. “The Industry 4.0 concept relies largely on the ability to design and manufacture smart and connected devices that are based on microelectronics technology. This evolution requires highly skilled technicians, engineers, and Ph.D.s, all of them well prepared for research, development, and manufacturing.” [88]

The need for problem solving and teamwork skills has been recognized for some time, but the evolution of curricula is not fast enough. All programs include some sort of capstone experience, but this alone is inadequate for teaching the breadth of soft skills needed. Particularly when developing technology for human use, the synergies of work with people from different disciplines and backgrounds is the key. A single capstone course is simply not enough. Human work in the Fourth Industrial Revolution is not meant to be discarded, but its role must transform in order to thrive and find new solutions to increasingly complex challenges. [89]

On the international scene, new programs are emerging by making use of 5G and cloud computing to interact in real time with international faculty. Curricula is integrated and modern. Traditional silos of engineering are broken down and pedagogy integrates theory, application, and mentorship. Hands-on projects are achieved through intimate integration of learning and doing with the acknowledgement of the interdisciplinary nature of the modern world.

The notion that education ends with the awarding of a degree is simply an outdated idea and is no longer true. As technology changes at an exponential pace, the learner must be refreshed and recalibrated, and brought along with the technology. Technology providers have the means to deliver material via the cloud and know what’s relevant via Big Data. Cybersecurity methods are used to keep each individual’s records confidential.

Summary of opportunity 6: Credentials and lifelong learning are becoming more valued by the Industry 4.0 workforce. Providing the means to learn at the pace of Industry 4.0 can be key to attracting the workforce of tomorrow.

System-level opportunities: Addressing societal issues and promoting cross-sector collaboration.

Opportunity 7:
Address the social determinants of work, now.

As described above, COVID-19 has made a profound impact on the academic ecosystem. Perhaps the most obvious impact is that disruption has accelerated the advancement of online courses. With careful coordination and collaboration, highly professional content can be created. There is no need for peer review as the crowd will vote with their clicks.

The authors of this paper had the unique experience of witnessing the impact of COVID-19. The authors’ work and data regarding the talent pipeline traces back to 2019 prior to the existence of COVID-19, but the deep dive research into the academic ecosystem and writing of this document occurred in the midst of the pandemic, between May and July 2020, in the U.S. Midwest. The consensus of the authors is that the challenges to the mechanical talent pipeline were inevitable. COVID-19 only amplified the challenges, made them more intense, and ramped up the urgency for reform. The authors agree with Krouse and the old heuristic, "necessity is the mother of invention." Now is not the time to hunker down and wait for the ecosystem to return to normal. Now is the time to act, while the academic system is in the midst of disruption.

Summary of opportunity 7: The social determinants of work have never been in a more chaotic state; now is the time to act.

Opportunity 8:
Promote cross-sector collaboration with other disciplines.

Several cross-sector opportunities were suggested for the civil engineering discipline in a paper by the Autodesk Foundation. [Deloitte paper: Supporting worker success in the age of automation]. Many of those opportunities also apply to mechanical engineering and associated trades:

1. Place-based initiatives add the context of broader public-private priorities.
2. Collaborations can be bolstered by connecting to national priorities.
3. Multiple government layers of activity are important for achieving outcomes.
4. Sharing of information is needed at the industry and national levels.

More prominent in the mechanical engineering discipline is the cross-sector collaboration problem that involves the ongoing struggle between product development requirements and manufacturing process planning. In the age of Industry 2.0 (the assembly line), the drive for high volumes, error-free quality, and affordability created a need for highly specialized work and rigidly specified product requirements. The manufacturing and product activities of mechanical product development grew apart, with each forming independent silos of operations. To compensate for these silos, techniques emerged such as "Design for Manufacturing" and "Design for Six Sigma."

These were invented to bridge the diverging fields of product and manufacturing. But new means of collaboration are required in mechanical engineering to not just respond to Industry 4.0, but to use Industry 4.0 to merge product design and making once again. Technology providers can provide the means to bring the two back together. This merging is particularly crucial when developing technologies that will involve extensive human interaction. [89].

Summary of opportunity 8: Cross-sector collaboration—building on and linking to initiatives from other disciplines such as civil engineering—represents an emerging and evolving opportunity to impact all of engineering, beyond the mechanical world.

Opportunity 9:
Stay engaged in a meaningful way for the long term.

As we have discussed in this report, technology is changing at an exponential rate and will continue to do so into the future. All the opportunities in this paper discuss ways industry needs to engage with academia in order to train engineers for tomorrow. This is not a one-time or one-off project. This engagement needs to continue and must keep pace with the technological changes that happen around us. In the future, industry and academia will jointly bear the responsibility of training engineers.

Summary of opportunity 9: Stay engaged for the long term.

Conclusions and Recommendations

With the completion of research objectives 1–3, the authors come to the following conclusions:

Industry 4.0 is producing profound ramifications for businesses' cost structure, work processes, and human labor. Some jobs will be eliminated while new and different types of work will emerge. This fact will require academia to rethink the curriculum to keep pace with change.

The talent pipeline is failing to provide sufficient quantities of workers, and the need for rapid reskilling in Industry 4.0 has become ever more urgent.

COVID-19 has created an economic situation that is fundamentally different from any previous crisis [9]. The global pandemic has accelerated the pace of change and disruption to a level not experienced before.

To successfully navigate the Industry 4.0 environment (and beyond), organizations will need to integrate five very different generations into their workforce. This will be no easy task, given the generational differences coupled with the shortage of qualified talent.

Industry needs to engage with both two-year and four-year educational institutions in new and dynamic ways, including K–12 systems.

Employability skills and components are most often undertaught or not included as part of a formal high school or college technical education today. Industry liaisons to academia are clamoring for more.

Community colleges cannot attract next-generation workers by offering lifelong job security in repetitive traditional trades. The nature of the work, opportunities to , and opportunities to explore new things must be developed, emphasized, and marketed to replace the traditional, stereotypical view of the machinist trades.

Generational differences are measurable and clearly evident in terms of behaviors, motivations, and competencies. Academic programs that worked for a past generation may no longer be effective as society rapidly evolves. Findings suggest that educators, industry leaders, and policy makers need to collaborate to make immediate and sweeping educational reform.

Many challenges on the academic supply side, including issues with retention of admitted students, are greatly affecting the number of students entering the education ecosystem. Inside academic programs, the pace of change driven by Industry 4.0 within academia is staggering, but so are the demands on companies that will become the employers of academia's newly minted engineers and technicians. STEM graduates and two-year students who are frustrated by the lack of academic progress can choose to avoid traditional corporate careers; plus, they now have options such as joining a startup or launching their own venture.

Students see value in portable credentials as means to open doors for careers, but they are less and less constrained to traditional school for those credentials.

With the completion of research objectives 4–5, the authors make the following recommendations:

On the supply side of the academic ecosystem, the authors recommend that technology providers: 1) get involved with active learning programs, and 2) promote the profession with new narratives that reflect the disruption and excitement of Industry 4.0.

Conclusions and Recommendations

Within academic programs, the authors recommend that technology providers: 1) engage with faculty to develop new curricula, and 2) develop new methods for reliable, transferable credentials.

On the exit side, the interface of academia to industry, the authors recommend that technology providers: 1) strive to develop graduates who are immediately ready to contribute, and 2) strive to develop graduates who are proficient in Industry 4.0 technologies.

For the overall ecosystem, of which academia is a part, the authors recommend that technology providers: 1) Not wait for COVID-19 to go away (as many academics are doing), but act now, and 2) promote cross-disciplinary collaborations.

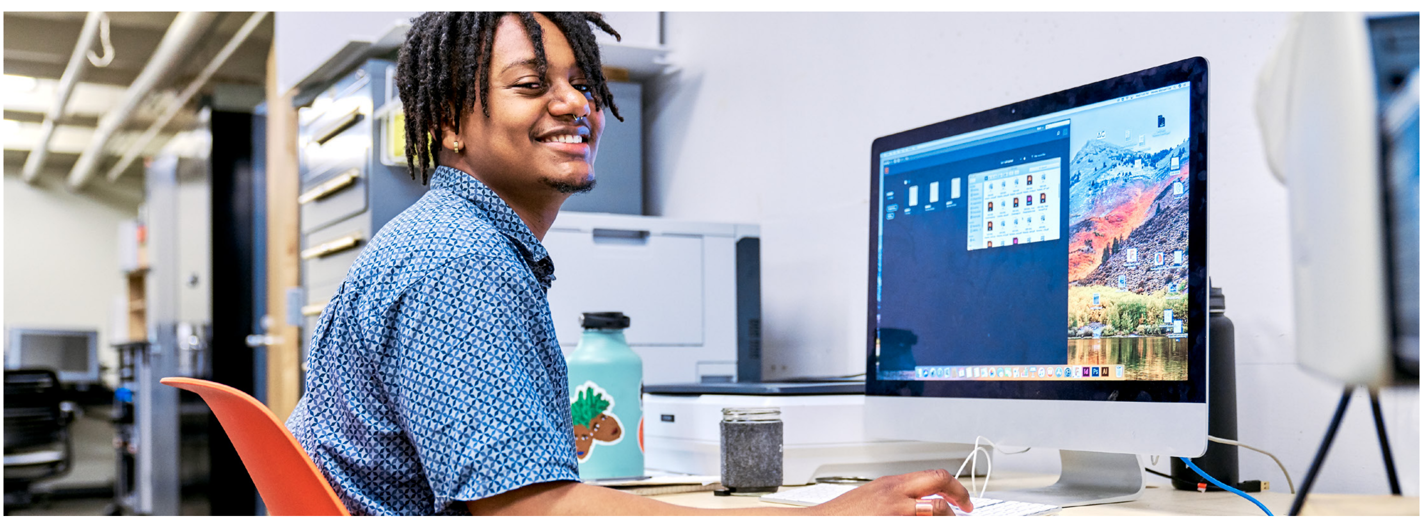
Concluding thoughts

Findings suggest that educators, industry leaders, and policy makers need to collaborate and initiate immediate and sweeping educational reform. Engineering and engineering technology education must incorporate contemporary Industry 4.0 subject matter, such as advanced software skills and AI courses at the reduction of some Industry 2.0 subject matter, such as differential equations with linear algebra. This is not to say students should not be exposed to understanding differential equations, but they should be exposed to it in Industry 4.0–applied ways.

Industry 4.0 workforce development reform also needs to reincorporate the social sciences.

Sociology, anthropology, psychology, and the research methodologies these fields employ are other important areas in need of reintegration. Some of these topics could be one- or two-credit offerings that blend human engagement, online modules, readings, and field experiments.

Faculty and students should also be skilled in areas that promote the development and application of business acumen, including the intersections of entrepreneurial thinking and leadership, as well as data analytics, decision making, and financial economics. These will be essential as new business models unfold and are created.



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