INTRODUCTION

Industry 4.0

In the spring of 2016 I travelled to Japan for a primer on the Industrial Internet of Things (IIoT) and Industry 4.0. What I saw there forever changed way I see industry and manufacturing.

I had been leading manufacturing companies for more than two decades; Chief Executive of two, and Chief Operating Officer of another. I thought I was cutting edge. I was floored.

I participated in a tour of a manufacturing facility comprising about 120,000 square feet. Forty or so huge machining centers, each the size of my office, grinded away on steel production parts. Every two machining centers were fed by one gigantic robot. Raw material was secured from stores and delivered to each robot by an Automated Guided Vehicle (AGV, think driverless fork truck). Upon completion of the machining process the robot retrieved the finished part from the machining center and handed it to the AGV which then delivered it to the next operation. 120,000 square foot plant, operating 24 hours each day, 5 days each week with……….12 employees.

Our next stop was a building perhaps a half mile away but it could have just as easily been half a world away. A plant schematic of the facility I had just visited appeared on a huge touchscreen hanging on the wall. As icons representing each piece of equipment were touched by a person, data reflecting cycle time, throughput, performance to standard, rejects, predictive maintenance, and more appeared in real time. When a piece of equipment experienced a failure, its icon flashed red and touching it produced information about the failure mode and lost production and a video then appeared next to the equipment icon and one of the twelve employees could be seen responding to the line down.

I was next provided a demonstration of the software used for predictive equipment maintenance. All of the equipment I had just seen was outfitted with smart sensors that gathered environmental and performance data. Temperature, pressure, vibration, moisture, current, disturbances and more were being monitored in real time and fed into an algorithm to predict equipment failures before they ever occurred – and to order replacement parts for equipment that would otherwise fail in the future. A robot would literally predict its own future failure and order its own replacement parts so they could be replaced before failure ever occurred.

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Industry 3.0

I came of manufacturing age in an Industry 3.0 world. Of course we didn't call it that, but that's what it was. Paper purchase orders arrived from customers and were entered manually in an MRP system to initiate a manufacturing order. Drawings travelled with the physical order. Operators used work instructions to manually adjust machine settings. Chemists physically removed samples from process tanks, manual titrations were performed and their results were entered on paper. Chemical modifications were ordered and made by physically carrying the chemical additions to the line.

Efficiency, productivity and yield data were gathered on a clipboard. Quality was judged by a department located hundreds of feet from the production line and reject data was recorded on a paper form.

Machine maintenance issues were raised when a mechanical problem caused rejects or when the machine stopped all together. Maintenance staff were alerted by a machine operator paging them over the public address system. Maintenance issues were triaged based upon the relative rank of the person doing the paging. Preventive maintenance was something to be performed, if ever, when the maintenance team wasn't busy responding to acute maintenance issues.

Orders to suppliers were faxed or emailed and receipts, packing lists and invoices were tracked manually. Customer orders were handled the same way.

I could go on but the point is obvious. The difference between Industry 3.0 and Industry 4.0 will truly revolutionize manufacturing and, in turn, education.

In drafting this report we drew from personal experience in working with educators across the United States, from research where appropriate, and through discussions with **some of the world's most influential people in the realm of Industry 4.0**. Really. Read on….

Industry 4.0 for Education

As a $6.6 billion American provider of industrial automation and information products, Rockwell Automation is on the bleeding edge of Industry 4.0 and IIoT and its Vice President of Global Business Development, Tom O'Reilly, shared his thoughts with us.

"[Rockwell Automation's] customers around the world in manufacturing are starting to recognize the benefits that IIoT and other new technologies can bring to manufacturing operations and businesses overall. Rockwell Automation brings this to life with our Connected Enterprise, but in many places there are skills gaps regarding advanced manufacturing technologies and processes, and this is something that urgently needs to be addressed by companies and education institutions."

O'Reilly's candid observation leaves a huge question for educators. How are we ever going to prepare people for careers in a manufacturing sector that is changing and will continue to change at warp speed? Either because they see the change themselves or because they are being encouraged by their industrial stakeholders many educators are themselves preparing for an Industry 4.0 world. As industrial hardware becomes "smart" and increasingly interconnected and networked and then produces considerably more data than ever before, educators recognize their need to quickly adapt.

But how? What aptitudes will be important for students to possess, and at what levels of education and for what career pathways? For this reason and to answer these questions we authored this paper.

TEACHING IIoT: Preparing Students and Learners for Industry 4.0

What is Industry 4.0? / The Education Building Blocks

Most answers to this question begin with tired explanations of the first three industrial revolutions and culminate in the revelation that Industry 4.0 – Cyber-Physical Systems – has begun. Blah, blah, blah.

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While Industry 4.0 can be summarized in a simple sentence, the technology, manufacturing systems, hardware, software and data analysis processes that underlie it are infinitely complex. It is for this reason that a logical, systematic and progressive approach to teaching it becomes extremely necessary.

Industry 4.0 can be summarized by six building blocks, and addressing each in appropriate complexity at progressive levels of education becomes integral to producing a career-ready individual who possesses the right combination of skills and abilities needed by today's advanced manufacturing companies.

Students at each level of education require level-appropriate exposure to and experience with each of the six building blocks. The building blocks are as follows:

Building Block 1 – Industrial Success Skills

Contrary to the perception of many, Industry 4.0 is not a revolution or end unto itself, it is not a destination. Industrial companies don't become Industry 4.0, they use it as a tool to continuously improve and drive waste out of their processes. Thus for an individual to reach the workforce Industry 4.0-ready they must have a basic understanding of the disciplines that underpin industrial success, including:

- An appreciation for workplace safety and safe work practices.
- An understanding of the basic throughput equation and the basic industrial need to maximize efficiency and productivity.
- An understanding of the Seven Deadly Wastes and how they manifest themselves in industrial and related processes.
- Familiarization with industrial Standardized Quality Systems.
- The ability to troubleshoot industrial processes and equipment.
- Soft industrial skills including collaboration, problem solving, discipline and time management.

Building Block 2 – Industrial Equipment and Technology

Widely viewed as the world leader in CNC Controls and Automation for industry, FANUC has led the charge to an Industry 4.0 world. Mike Cicco serves as President and Chief Executive Officer of FANUC America. "It's important that our people know how to write analytics to derive useful data," Cicco suggested during his participation in our research, "but it's equally important that that person has a deep knowledge of what manufacturing is in the first place."

Cicco's observation is astute. As industrial equipment collects more and more data about its own condition and performance, the need to discern usable and pertinent data from that which is not becomes vital. If the person performing analysis or creating algorithms does not understand the underlying industrial technology, their ability to perform such tasks will be severely deficient.

Thus Building Block 2 is the understanding of the production and manufacturing equipment that underlie Industry 4.0.

Examples of such equipment and processes include Industrial Robotics, Machining, Extruding, Casting, Manual and Robotic Welding, Conveyors, Mechanical Drives, Mechanical Fabrication, Forging, Stamping, Forming, Molding and more.

Understanding basic manufacturing technology, such as AC/DC Electricity, Thermal Science, Pneumatics, Hydraulics, Fastening, Product Finishing, Materials and Metrology is also of great value.

Building Block 3 – Smart Sensors and Smart Devices

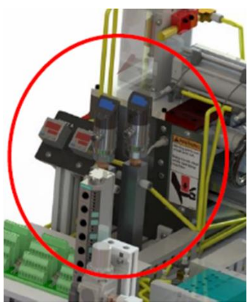

Figure 1: A smart pressure sensor on a mechatronics system. Smart sensors and devices are integral to Industry 4.0

At the core of Industry 4.0 are Smart Sensors and Smart Devices. This technology gathers virtually infinite volumes of information about its own environment and then uses embedded intelligence to complete programmed functions before sharing the information with other systems and devices via computer networks and the Internet.

Smart Sensors and Devices take a wide variety of forms and perform a wide variety of functions. Examples include vacuum sensors that detect the condition of vacuum pickup, ultrasonic height sensors, and current and pressure sensors.

Smart sensors can also measure and act on data pertaining to conditions such as temperature, proximity, the presence and levels of smoke and gas, fluid level, humidity, force, torque and acceleration.

In addition to his role as the president of Jeffersonville, Indiana's skills-based, interactive technical learning provider Amatrol, Inc., Paul Perkins serves as Chair of the State of Indiana Workforce Innovation Council and on the National Governors Association of State Workforce Board Chairs.

Perkins' company is a leader in delivering IIoT learning systems and he believes that a student's knowledge must expand beyond a simple understanding of smart sensor and device types. "It's really giving students the opportunity to experience working with each type of data, including analog data, discrete on/off data, position, torque, pressure and more so they understand how to embed data in the device and how to retrieve it," says Perkins.

Building Block 4 – Control Systems

Industrial Equipment and Technology perform the work of manufacturing; machining, forming, extruding and molding materials into usable products. Smart Sensors and Devices monitor the process of doing so and provide direction and feedback to the process, and Control Systems oversee the processes. Functioning in real time to control the entire manufacturing process these systems serve as the brain of each operation.

To be prepared for an Industry 4.0 world a student's understanding of these systems is imperative and should include an aptitude in the following:

- Programmable Logic Controller (PLC) Operation and Programming
- Safety PLC Operation and Programming
- Operator and Human Machine Interfaces
- Distributed I/O
- Electronic and Variable Frequency Drives
- Motor and Motion Control
- Power & Control Electronics

Building Block 5 – Connectivity and Networking

If Control Systems are the heart of Industry 4.0 then networks carry the lifeblood. Industrial networking isn't anything new – Industry 3.0 was full of industrial computer networks. What changes in an Industry 4.0 world is the increasing use of Internet Protocol in the overall system or "Fieldbus". As industrial equipment is increasingly internet connected a wide range of issues arise.

Cisco claims the spot as the worldwide leader in IT and Networking and Brian Tantzen is the General Manager of the company's Connected Industry and Manufacturing Business Unit. Also leading the formation of Cisco's Industries Product Group which drives engineering and cloud applications for Cisco's industry and IoT products and solutions across multiple vertical markets, Tantzen participated in our research.

"The big opportunity for the future are the people who can do both [Operational and Information Technology]," says Tantzen. "Cisco is providing factory networking, security and training for the move from proprietary systems to IP-based systems and working to bridge these two worlds together."

As these two systems converge students will require greater understanding of the computer networks that carry the data produced by smart devices and control systems. This understanding must include learning multiple technologies, including Network Servers, Distributed Servers, Routers, Switches, Gateway Devices, Ethernet, Foundation Fieldbus, Profibus, Wireless Communication, Linking Technologies and Multi-User Applications.

Perhaps an industrial company's most significant anxiety at the advent of Industry 4.0 is the idea of connecting all of its manufacturing intellectual property to the internet. The very intrinsic value of many such companies lies in the processes and systems used in manufacturing their products and the risk that this property could be stolen is of grave concern.

Concerning also is the risk of a supply or manufacturing system interruption resulting from the introduction of a virus or ransomware into an industrial company's computer network. ***As Tantzen puts it, "Network Security is one of the barriers to implementing Industry 4.0 technology. There is a growing wave of attacks in factories and catastrophic risk they could be facing as a result. Factories were intentionally built to be air gapped and now we're connecting them."***

For these reasons a student's appreciation for and working knowledge of network security tools and appliances is imperative.

Building Block 6 – Inform-Actionable© Data

It's a made-up word but it fits perfectly. More data was created in the last two years than was created in the last 5,000 years of human existence. (Harris, 2016) For many industrial companies one challenge of Industry 3.0 was a lack of data. As companies embarked on continuous improvement projects many lacked the necessary information to perform analysis, draw conclusions and take action.

With the presence of smart sensor and smart device technology, outlined in Building Block 3, and the resulting nearly infinite abundance of data the problem in Industry 4.0 will quickly become not the absence of data but way too much of it.

Thus, individuals possessing the skills and knowledge necessary to analyze data and prescribe corresponding action will be of absolute necessity in the era of Industry 4.0.

As FANUC's Cicco noted, "[In a connected environment] the amount of data pouring out of a piece of industrial equipment at any given time requires new analytics on an ongoing basis. Some data is important to some and other data is important to others. Finding people who can sift through the data is really important."

In addition to analyzing data, a student's ability to write the analytics, the computerized analysis of industrial information and data, will be highly valued. Not that every individual moving to an industrial employer will need to possess this skill, but, **as Cisco's Tantzen shared with us, there will be a considerable role for data scientists with an aptitude for statistics, regression analysis, lightweight programming and familiarization with SQL, SSAS and R.**

Finally, students will require a working knowledge of cloud-based production control and an understanding of how production data, gathered using Industry 4.0 technology, is utilized to manage an entire industrial enterprise.

Of all the building blocks, Block 6 is perhaps the most challenging to align with a student's educational needs. As Operational Technology and Information Technology continue their convergence the point at which one leaves off and the other begins will become increasingly blurry and eventually overlap. Thus the need to ensure that, at each level of education and in each educational program, the importance of inform-actionable© data and the processes by which it is gathered and acted upon is communicated and understood.

Teaching Industry 4.0 at Each Level of Education

From his higher education beginnings as a Bachelor of Science Industrial Education student at Wisconsin's Polytechnic University, University of Wisconsin – Stout, Dr. Robert Meyer has risen to the position of Chancellor of the same institution. His decades of experience in between – at multiple levels of education – place Meyer in a unique position to assess the need for Industry 4.0 and IIoT exposure at every educational level.

"It really starts with how you prepare talent and engage students in a way that energizes them and gets them thrilled about careers in industry and manufacturing early on," says Meyer. "If students aren't energized at a young age there are no career pathways to Industry. We invest significant time and energy developing young people who understand the Internet of Things and that is important. But we also need teachers who understand the technology. If teachers aren't able to create interest in K-12 learners then it's all for naught."

More than any other factor, a student's interests and experiences while in middle school and high school shape their career pathway. (ERCA, 2015). Thus the path toward creating the Industry 4.0 workforce of the future begins not at the community college or even the high school, but in generating interest in the underlying technology and soft skills as a student begins his or her educational journey. In elementary school.

From there, the technology and soft skills must then be presented and learned in progressive fashion throughout a student's education pathway, continuing through secondary education, to and through 2-year and 4-year colleges and universities.

We continue by outlining the necessary curriculum and pedagogy at each level, as always returning to the question of what should be taught and what students should be learning.

Level 1 – Elementary School

Andrew Gillies invested nine years of his career as a creative teacher and three as a STEM education consultant. Today his passion is developing curriculum, eLearning and training equipment intended to instill a sincere interest among young students in STEM Careers. Says Gillies, "There is a dichotomy between work and education in regard to STEM. Educationally, STEM emphasizes science and mathematics. Outside of education, the majority of STEM occupations and the drivers for economic growth are based on engineering and technology. (Gillies, 2015)

As the title of Gillies recent article implies, in an Industry 4.0 world the time has come to put the Technology and Engineering into STEM. While expecting elementary students to learn the finer points of advanced industrial technology would be neither practical nor effective, laying a foundational understanding of basic industrial processes along with design and problem solving methodology is of critical importance.

The preparation of students for the world of Industry 4.0 must include the right combination of theoretical learning reinforced by practical, hands on investigation through experiments and projects that engage students in a fun and enlightening fashion and reinforce important soft skills.

For instance, a small group of elementary level students might participate in a basic engineering lesson offering special emphasis on critical thinking and creativity. Problem-solving and design, important parts of the engineering process, can be learned alongside the scientific discipline. Using their new skills, the students might engage in a hands-on activity such as creating a simple low voltage electrical circuit. The students can then gather basic data about the circuit, log and analyze the data and then communicate what has been learned. In one lesson the students have simultaneously learned a new scientific discipline, reinforced the theory with hands-on learning and also gained data collection and analysis, collaboration, teamwork, and written and verbal communication skills.

This cycle can be repeated over and over – across myriad Industry 4.0 foundational disciplines - to instill a wide range of theoretical knowledge, hard skills and soft skills in each student. Platforms already exist to ensure that this learning is consistent with mandated requirements such as Next Generation Science Standards or the International Technology and Engineering Educators Association Standards to Technological Literacy.

A foundation can be laid which provides students with the fundamental skills and aptitudes for the advanced manufacturing careers of today and tomorrow. While such content will and should be broad, specific to Industry 4.0 the curriculum should include aspects of the following:

- The application of **Math and Basic Algebraic Reasoning** to perform analysis, and create and understand patterns and relationships.
- Basic **Scientific Investigation and Reasoning**.
- The **Engineering Design Process** including an emphasis on critical thinking, creativity and problem solving.
- **Physical Science** including an understanding of light, force, motion, magnetism and electricity.
- **Data Collection, Logging and Analysis** to introduce the fundamentals of analytics and problem solving.
- **Science Practice** including safety, inquiry, modeling, investigation, exploration and communication.
- The **Foundations of Automation**, robotics and basic coding and programming.

Level 2 – Grades 6 to 10

After earning his Master's Degree in Education, Mike Dietrich taught middle school science, social studies and special education in the Milwaukee Public School District for six years. Today he works with K-12 educators across the Midwest, providing learning systems that prepare students for STEM and Advanced Manufacturing pathways.

"At many middle schools, students receive exposure to computer programming and the basics of coding through free computer programs that enable them to, for example, write a program that

guides a snake through a path. That's better than nothing," Dietrich states, "but to be prepared for the Industry 4.0 world they must quickly move beyond that to projects that are more applicable to the types of processes that exist in industry and that expose them to incredibly interesting and rewarding career paths in advanced manufacturing and STEM."

Industry 4.0 education at the middle school level starts to look a little more like advanced manufacturing. Continuing with standards-aligned curriculum, and group project-based active learning supported by a solid theoretical framework, students become more familiar with basic industrial systems and components in a fun and engaging fashion.

Coursework in disciplines such as the following form the basis upon which a more advanced comprehension of Industry 4.0 technology and processes can be built. Curriculum designed to deliver Industry 4.0 learning might appear as follows, with each section comprised of 15 to 20 class hours:

- **Engineering Design** including engineering problem solving, modeling, prototyping, communicating engineering design and demonstrating engineering design skills in a hands-on setting.
- **Manufacturing Technology** including types of materials and their mechanical properties, different manufacturing processes, design for manufacturability, waste measurement and reduction and a project in which they design a production part and use a basic manufacturing system to produce it.
- **Rapid Manufacturing** including rapid tooling, mechanisms, design loops, injection molding, additive manufacturing and a rapid prototyping and manufacturing project.
- **Electronics Technology** including and understanding of Ohm's Law, the design of a simple circuit, bread-boarding and a design project that requires the student to review a simple electrical circuit and then improve its function.
- **Industrial Robotics** in which students become familiar with industrial machines and basic machine control systems, the control loop, sensors, actuators, various types of industrial robots and how computers are used in manufacturing. A design project might require a student to utilize a simple robot kit to design a basic industrial robotic system.
- **Mobile Robotics** in which students learn the basics of automated guided vehicles and mobile robots. Content might include an introduction to mobile robots and their control systems, the sensors and servos that are integral to mobile robot technology. The final project might involve designing, constructing and creating the control system for an Automated Guided Vehicle.
- **Mechatronics** including the exploration of basic mechanical principals, simple machines, mechanical systems, gears, basic pneumatics and hydraulics, and lever principals. A design challenge might be to engineer a basic fairground ride model using an engineering construction kit.
- **Basic Computer Science** including Computing Concepts, Algorithms and Problem Solving, Inputs and Outputs, Data, Constraints and Variables, Documentation and Testing. The final design project could require the students to build a simple computer controlled system such as a model elevator.
- **Basic Robotic Programming** including the design of basic algorithms used in problem solving, additional training in Inputs and Outputs, Data, Constraints, Control Structures and a series of design projects to develop the skills needed to control a range of robotic systems.

Level 3 – Grades 9 to 12

"Young people today understand connected devices better than anyone," asserts FANUC's Mike Cicco. "As they continue to progress in their education they will see the benefit of Industry 4.0. From the day they were born, they could see smart technology open a garage door, turn on lights or use it to check statistics and scores in real time. Transferring that understanding to industry will be a natural thing for them."

Cicco is completely correct in his observation that most young people are considerably more adept at using smart technology than are their senior counterparts. For this reason, such knowledge may not be the most significant hurdle in producing an Industry 4.0 student. Instead, what many currently lack is exposure to authentic manufacturing technology and equipment.

That Levels 2 and 3 overlap by two grades is no accident. As students move from middle to the secondary level they will require an increasing level of familiarization with the types of systems and equipment with which they will interact if they choose a career in industry.

Many industrial employers lament the shortage of young people interested in industrial careers. However, a peek into their local high schools often reveals the source of the problem. If students don't gain exposure to authentic industrial equipment in the years during which perceptions of certain careers are formed, there is little chance that industrial careers will be part of their decision process as they consider their futures.

Sheboygan, Wisconsin's Red Raider Manufacturing program serves as one example of how school districts should approach the preparation of students for careers in advanced manufacturing. One of the most unique aspects of Red Raider Manufacturing, where local industry helped fund a $5 million technical education renaissance in two high schools, is the focus on advanced factory automation technology and skills. "Manufacturing isn't about screwing three screws into a manifold," noted Sheboygan South High School Principal Mike Trimberger, "it's about operating the equipment on an automated production line. Skills like welding and metal fabrication are foundational, we need to take those skills and utilize them to operate and program robots that cross any sector; any area." (Dietrich, 2016)

Figure 2: A student at Sheboygan, Wisconsin's South High School operates an industrial grade FANUC robot as part of the school's Red Raider Manufacturing program.

This statement, when considered in conjunction with Cicco's earlier assertion that a base understanding of manufacturing technology is a critical building block in a student's preparation for Industry 4.0, demonstrates the absolute imperative that such learning be part of Industry 4.0 curriculum.

It is at this stage that learning must transition from a theoretical understanding reinforced by basic active learning designed primarily to be fun and engaging to more advanced understanding of industrial technology, combined with authentic industrial skills and hands-on training. At the secondary level, Industry 4.0 curriculum and programs might include the following, each consisting of a student learning the technology, seeing it demonstrated using a hands-on training system, and then cementing what they have learned by performing the skill themselves:

- **Basic Manufacturing Process Skills** including Computer Aided Design, Print Reading and Computer Aided Manufacturing.
- **Electrical Systems**, including basic AC/DC electrical systems and circuits, electric relay control and electric fabrication.
- **Mechanical Systems** including mechanical fabrication, structural engineering and mechanical drives.
- **Industrial Fluid Power** comprised of coursework in basic and advanced pneumatics and hydraulics, electric sensors and electro-fluid power.
- **Industrial Electronics** and **Computer Control**.
- **Thermal Technology**.
- **Automation Systems** using authentic industrial grade robots.
- **CNC** equipment and simulators.
- **Welding Equipment** and virtual reality welding training systems.
- **Mechatronics** integrating the above technologies in a fashion that enables the learner to understand how basic industrial technologies can be combined into an industrial production line.

Many school districts make the mistake of assuming the presence of industrial equipment equates to learning. While the presence of such equipment is better than no equipment at all, welding equipment, CNC machines and robots in the absence of proven curriculum to guide instructors and teachers in delivering the kind of learning valued by industry may be of limited value in preparing students for industrial careers.

Figure 3: Hands-on Industrial Skills-Based Training Systems used to deliver industry-relevant authentic learning

In addition to instilling a base understanding of manufacturing technology, curriculum and learning in the areas of computer science, coding and programming, control systems and networking are equally important.

Base manufacturing skills training when combined with computer science and networking knowledge provides an ideal springboard into project-based learning opportunities that can continue to build Industry 4.0 skills. For instance, the design and manufacture of a water desalination system, ergonomic manipulator, automated drawbridge, automated can crusher or a hovercraft. Projects of these sort that build valuable design, collaboration, problem-solving and system fabrication skills would all be appropriate at the secondary level.

Level 4 – Technical and Community College

Preparing students at the technical and community college level for Industry 4.0 reflects a continuation of the learning they acquired during secondary education, with even greater emphasis on authentic industrial applications. Whether a student is pursuing a degree or certificate in Electro-mechanical technology, Metal Fabrication, Welding, Machine Tool or CNC, Industrial Maintenance Technology, Automated Systems Technology. Mechatronics or other industry related endeavor, the equipment with which they perform their jobs, the systems that control that equipment and the networks by which they will be connected are all fundamentally related to Industry 4.0.

While considerations for each and every program type are outside the scope of this report, suffice it to state that every such program must examine the degree to which Industry 4.0 will affect the industrial environment its students will enter upon graduation and ensure that the relevant level of learning in each of the six Building Blocks addressed earlier in this document is delivered.

The following considers the manner in which Electromechanical Technology, Industrial Maintenance Technology, Automated Systems Technology, Mechatronics and similar programs perhaps otherwise labeled, deliver learning specific to Industry 4.0 and IIoT.

Inherent in our assumption is that students have already gained the requisite level of knowledge in Building Block 1 (Industrial Success Skills) and Building Block 2 (Industrial Equipment and Technology). It is further assumed that they have an appropriate level of knowledge in Building Block 4 (Control Systems).

With this underlying level of familiarity with industrial technology and control systems, preparing students for the world of Industry 4.0 requires learning in and exposure to functioning production systems encompassing technologies such as programmable logic controllers, fluid power, actuators, variable frequency drives, motor control, motion control, and so on.

Further, they must become familiar with basic automated manufacturing operations including inventory control, inspection, sorting, assembly, torqueing, testing, machining, storage and production control.

Finally students must gain an understanding of IIoT technology, including smart sensors and devices (Building Block 3), Connectivity and Networking (Building Block 5) and Inform-actionable© Data (Building Block 6).

In our research the most effective way of delivering this learning is through a combination of two types of learning systems.

IIoT Learning System Type 1 – Mechatronics Learning System: A system that enables students to acquire IIoT and other skills on a functioning production line that produces a product in conjunction with standardized proven and current-to-the-day curriculum designed specifically to deliver IIoT learning.

Such systems, often referred to as Mechatronics Learning Systems, such as the one utilized in the Integrated Manufacturing Center at Waukesha County Technical College in Waukesha, Wisconsin, enable students to learn manufacturing operations such as Pick & Place Feeding, Gauging, Part Orientation, Sorting, Buffering, Robotic Assembly, Torqueing and Inventory Storage. In the preparation of this report we reviewed several such systems.

Imperative in the design of such a system is the presence of IIoT technology and the curriculum to support it. For instance, one such system integrates barcoding, radio frequency identification, machine vision, a smart stack light and smart proximity, pressure and positioning sensors into its system. To reiterate, however, it is not nearly enough for the technology to be present, it must be supported by curriculum that facilitates learning.

Figure 4: President Donald Trump and daughter Ivanka pictured before a Mechatronics Learning System at Waukesha County Technical College in Waukesha, WI.

While smart sensors and devices are critical to IIoT learning, curriculum must also include learning in Building Block 5, Connectivity and Networking. For example, one such system allows users to connect smart devices, controllers and other intelligent devices on a local area network (LAN) providing control and data acquisition throughout the system. On this system, students learn how to set-up, configure and troubleshoot various types of topologies using network switches and other hardware. Further, they learn how to connect the LAN to the Internet and use IT Security with both managed and unmanaged network hardware.

Wireless Network learning is also a key part of IIoT, and systems should enable students to connect programmable controllers and integrate them into the Mechatronics System wirelessly.

Further, as suggested in Building Block 6, Network security is non-negotiable, and a Mechatronics System designed to teach IIoT must enable protected data to pass between the Internet and a plant ERP or MRP system in a controlled manner that protects unauthorized access and enables students to gain a basic understanding of network security.

An IIoT Mechatronics Learning System must provide students with an understanding of how to control and manage a complete production system by accessing production data and analysis via the internet on smart phones, tablets or PC's.

Finally, the system must be programmable and configurable by the students and teachers. A system that merely runs a production process, with little or no interaction, programming, configuration, troubleshooting or control performed by the student offers relatively minimal opportunity for authentic IIoT learning.

IIoT and Industry 4.0 technology is evolving much too fast for a single teacher, instructor or even department to attempt to "go it alone". In many cases, curriculum could become outdated in as few as twelve to eighteen months. Thus, a Mechatronics Learning System, delivering learning in the proper IIoT disciplines, backed by proven curriculum that is literally updated as often as daily, must be an integral part of teaching Industry 4.0 at the community or technical college level.

IIoT Learning System Type 2 – IIoT Flexible Manufacturing System - As an extension of or in addition to a Mechatronics Learning System backed by standard curriculum, a flexible manufacturing line placed directly inside a learning environment can provide significant opportunities for delivering IIoT and Industry 4.0 Learning.

As President and CEO of Gateway Technical College in Southeastern Wisconsin Bryan Albrecht represents his institution on more than fifty local, state and national boards, in addition to leading a team of more than 600 education professionals.

"The integration of the cyber and physical world has revolutionized the way work is performed," Albrecht told us. "Industry 4.0 protocol driven by integrated industrial data systems has created new career paths for technical education. At Gateway Technical College we have begun to align our telecommunications training with engineering and manufacturing. Our goal is to expand traditional IT networking and data management careers through manufacturing application careers like mechatronics and manufacturing system engineering."

Indeed, preparing students for rewarding careers in Industry 4.0 careers will require those at the community and technical college level to view their programs in new ways and to collaborate across disciplines combining technologies studied in a wide variety of college programs.

One system enabling this type of collaboration resides at Chippewa Valley Technical College (CVTC) in Eau Claire, Wisconsin. The system was designed from the ground up specifically as a teaching tool to deliver learning in the latest Industry 4.0 and Industrial Internet of Things (IIoT) technologies.

The system is literally a fully functional manufacturing system which machines, engraves and assembles a made-to-order, custom USB Flash Drive. It includes four robots identical to those most widely used in industry and the same machining center used in the manufacture of the Apple iPhone enclosure.

Figure 5: This Flexible Manufacturing System at Chippewa Valley Technical College in Eau Claire, Wisconsin, was designed to deliver IIoT and Industry 4.0 learning.

The CVTC production line integrates industrial grade control system technology and a wide variety of IIoT smart sensors to monitor line performance at the point of production, as well as remotely via the internet. Human Machine Interfaces located at each manufacturing operation deliver real-time data including throughput, cycle-time, reject rates, performance to standard, uptime, preventive and predictive maintenance information and more.

Pertinent production data can be monitored via a tablet computer or on a computer screen in a classroom located any distance from the production line. All production data can be collected in real-time and exported for use in analysis and predictive analytics.

In addition, the system offers learning and related certifications, supported by curriculum, in the Industry 4.0 fields of Automation, Robotics, Programmable Logic Controllers, Human Machine Interfaces, CNC Programming, Setup and Operation, Laser Engraving, Networking, RFID, Barcoding, Variable Frequency Drives, Material Handling and Troubleshooting.

Systems like these form an ideal capstone to an Electromechanical, Industrial Maintenance or Automation Technology program. CVTC's intention is to challenge its students to continuously improve and modify the system over time, providing them the opportunity to hone their creative problem solving, design and collaboration skills.

Level 5 - Four Year College and University

The University of Wisconsin Milwaukee's Connected Systems Institute is working with a half-dozen companies on technologies tied to the IIoT. (Still, 2017)***. UWM's Chancellor Dr. Mark Mone participated in our project and shared his thoughts on Industry 4.0.***

"In today's connected workplaces," Mone noted, "particularly in industrial and manufacturing settings, it's imperative that the educational landscape provide our students with IoT and Industry 4.0 concepts and tools. The value and impact of our graduates will increase commensurate with such understanding and application. Systems thinking alone is insufficient, as we need to eliminate functional walls and boundaries, replacing them with connectivity across engineering, manufacturing, IT, Supply Chain, HR, and other business functions."

Mone's observation is spot on. As Operational Technology and Information Technology come together, the silos that have historically existed in industry, and for that matter higher education, must come down. No longer can the industrial engineer hide from the systems engineer, as their successes and failures will be inextricably linked. While an analysis of what IIoT learning should be delivered in a wide variety of university level programs is well outside our purview, we are watching closely as progressive higher education institutions such as UWM continue to find ways to deliver IIoT learning across multiple disciplines.

Certainly, learning in each of the six Building Blocks must be delivered at the university level, across multiple programs and disciplines with the specific content and depth of coverage varying by program and degree.

In delivering such learning, several institutions have integrated open-ended manufacturing systems similar to the one at CVTC described above.

Such a system, infinitely flexible as technology and learning needs change, provides higher education students with the opportunity to become familiar with basic industrial success skills and technology, smart sensors and devices, control systems, networking, security and data analytics and to dig deep into those disciplines specific to their programs and majors.

Further, a flexible manufacturing system enables faculty to develop systems around curriculum and likewise curriculum around the specific technology integrated into their institution's system.

Finally, a flexible manufacturing system enables institutions and programs to perform research and innovate new technologies with the ability to integrate them directly into an industry-grade manufacturing system.

Summary

The advent of Industry 4.0 is already having and will continue to have a profound impact on Industrial and Manufacturing employers. Already suffering from a lack of skilled talent, this problem will become even more acute for them in the absence of a deliberate, concentrated and holistic approach to preparing students at every level of education with the requisite aptitudes and skills to interact with and leverage IIoT technology.

Truly grasping Industry 4.0 requires an understanding of each of the Six Building Blocks; Industrial Success Skills, Industrial Equipment and Technology, Smart Sensors and Smart Devices, Control Systems, Connectivity and Networking and Inform-actionable© Data.

While the degree to which each must be mastered varies greatly depending upon educational discipline and level, possessing elements of each of them will be of utmost importance if a student is to thrive in the world of Industry 4.0.

Beginning in elementary school, students must be equipped with foundational skills that will prepare them for incremental learning. As they progress through middle school, learning must be comprised of engaging and fun theory and projects that begin to familiarize students with authentic industrial technology.

Secondary students on potential industrial and STEM career pathways must be provided an opportunity to secure knowledge and skills in a variety of base manufacturing disciplines and to engage with authentic industrial equipment backed by best available curriculum.

Learning at the Community and Technical College level must also include base manufacturing theory and skills followed by deep involvement with authentic IIoT technology. This learning is best delivered first though a Mechatronics Learning System supported by standardized curriculum and then via an open-ended authentic manufacturing system.

In the realm of higher education, providing Industry 4.0 learning across multiple disciplines and programs will be extremely important as traditional lines between technical roles are crossed in both education and industry. Several institutions are delivering IIoT learning through the utilization of an open-ended system that allows for technology familiarization, innovation and research.

We began this report with an observation about an Industry 4.0 enabled industrial operation in Japan. What we saw there blew us away, and for us was a harbinger of an industrial sea change during and following which nothing in the industrial world will be the same. Manufacturers and Industrial companies are faced with the single greatest transformation seen in a generation and perhaps in several generations. Among the many challenges this shift will present will be a need for talent well-versed in Industry 4.0 technology and thus the demand of industrial employers upon our education framework will rise to levels not seen before. Are educators ready?

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