A Collaboratively Designed Learning Platform to introduce i4.0 technologies and Concepts in Applications Supporting The Process Industry

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Abstract

Industry 4.0 technologies can radically transform the process industry but face adoption hurdles due to the limited number of skilled practitioners within the workforce. To address this growing skills gap in the workforce, Endress+Hauser, in partnership with Purdue University, is developing a new Intelligent Process Laboratory that will serve as a showcase system to demonstrate the Process Industry and the capabilities of Industry 4.0 technologies. The project deliverables will present a technology forward perspective of the industry to a new generation of students. The industry-led effort drives multiple senior capstone experiences developing training systems and a showcase continuous demonstration system. The output of this collaboration is a set of permanent instructional and demonstration platforms housed in a new high-visibility laboratory. These systems will provide realistic data for activities in numerous courses delivered to support a new major (Smart Manufacturing Industrial Informatics) focused on applying Industry 4.0 technologies in the Process and Manufacturing sectors. This paper details the project goals and timeline, leadership strategies, and industry collaborations with faculty and students throughout the effort.

Overview

The fourth industrial revolution promises improvements in efficiency, worker safety, and environmental impact yet unrealized. Technologies including Artificial Intelligence, Big Data, Cloud Computing, and others offer the potential to revolutionize manufacturing processes and career pathways. While the premise of Industry 4.0 has existed for nearly a decade and the driving technologies continually improve through robust research and development activity, the implementation of Industry 4.0 enabled solutions has been sluggish. However, the challenges of the COVID-19 pandemic have pushed the industry to increase its adoption of systems that augment workers and provide a safer working environment.

The increasing prevalence of Industry 4.0 technologies in the process industry amplify an already significant skilled labor shortage in the US. A further hindrance is the low public visibility of the activities and work roles in the process industries, often only visible in challenging applications with inherent safety risks, security concerns, and intellectual property protections.

The first step to improving the workforce shortage is to improve awareness of the industry, its impact, and its career paths to the next generation preparing to enter the workforce. A technology-forward showcase of the process industry can recast perspectives and entice students and parents to further explore and consider opportunities in an industry with limited public

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visibility. Simultaneously, enabling the showcase to be a key element of instruction can drive knowledge development through engaged learning with industrial-grade systems in environments not impacted by production timelines or economics.

Advancing Process Industry Education

Purdue University is Indiana's land grant university tasked with improving the economy and outlook for the state and nation. The manufacturing sector is the most significant component of the Indiana economy [1]. It stands to benefit significantly from adopting Industry 4.0 technologies or be harmed by failures to evolve. To support this effort, the State of Indiana, in conjunction with Purdue University, is developing the Gateway Complex at Purdue University, a 250,000 square foot instructional and research facility focused on Industry 4.0 technologies [2].

In conjunction with the Clean Energy Smart Manufacturing Institute [3], Purdue University is developing a new Smart Manufacturing program with reference laboratories forming a horizontally and vertically manufacturing ecosystem in the new Gateway Complex. This ecosystem will include an Intelligent Process Laboratory housing multiple training systems and a continuous process showcase system. The development of this technology-forward laboratory requires industry insight and expertise to ensure that applications, technologies, configurations, and use cases align with standards and industry trajectory.

Purdue University and Endress+Hauser USA have a well-established history of partnering to increase awareness of the process sector and deliver improved learning experiences capable of presenting real-world challenges in the classroom and laboratory [3]. The first collaboration was in 2014 with a capstone project, the Purdue Integrated Process Education System (PIPES). The fully operational system was designed and constructed during a yearlong capstone project undertaken by senior students in Purdue's Manufacturing Engineering Technology degree program, later serving as a teaching and learning tool for students and faculty. In the ensuing years, this successful collaboration and relationship expanded to support multiple capstone projects annually, advisory board participation, cooperative education program participation, and regular engagement at campus career fairs.

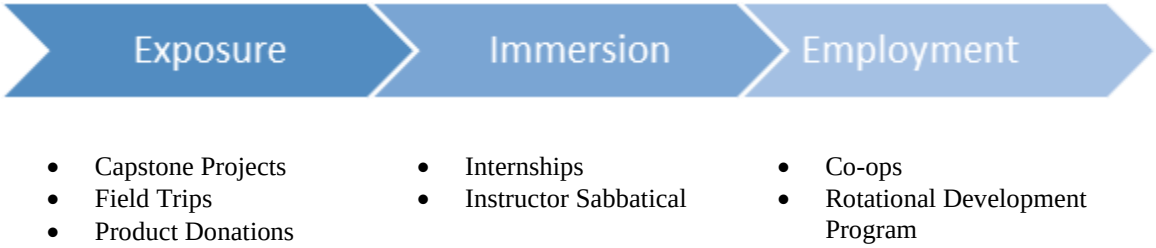

Fig. 1. Endress+Hauser partnership continuum.

Strategy

Endress+Hauser leadership immediately voiced strong support for the program and a willingness to help develop the Intelligent Process facility. Early engagements in the summer of 2020

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included discussions of the desired project scope, resource requirements, and timeline with a completion date of December 2022.

Initial discussions between the engineering and workforce teams at Endress+Hauser and faculty focused on determining the facility's core capabilities resulting in a consensus that two different solutions were needed to meet all educational goals. A continuous showcase system would produce rich context-specific data that could support higher-level investigations, including analytics and machine learning activities. An offline training system would introduce and allow students to engage with the instruments, technologies, and processes used in the showcase system.

The success of the PIPES project encouraged all to seek out maximum opportunity for student engagement in the design and development stages. It was evident that the complexity and the use of emerging technologies in the showcase system would make a meaningful and engaging student experience very challenging. The training system would require a less complex solution based on proven designs, allowing for a bounded student design and development experience suitable for senior capstone.

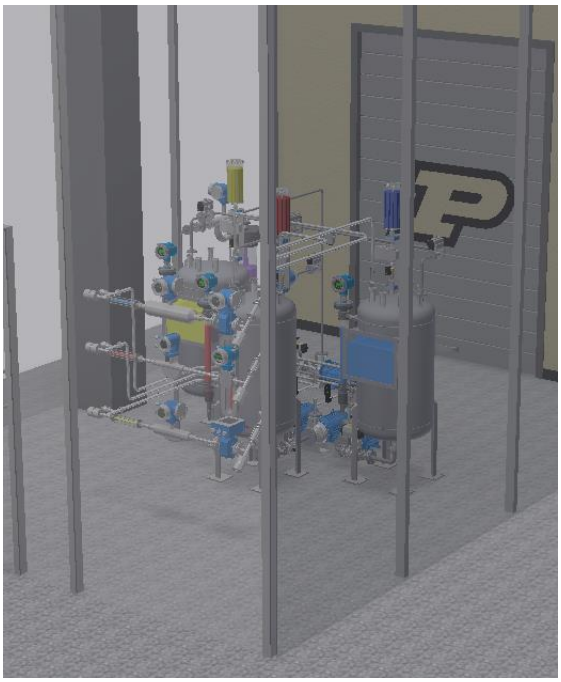

Fig. 2. Continuous process system.

Engaging Students

Two consecutive senior capstone experiences are needed to complete the development of the training system. The first capstone launched in January 2020 focuses on building and testing the platform, control systems, interfaces, computing surfaces, and communications systems. The second capstone launching in January 2021 focuses on programming the system, integrating the

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system with on-premises and cloud systems, and developing mixed reality solutions for training, operation, and maintenance.

The capstone project is a two-course sequence with multiple defined deliverables and assessments from faculty and industry [5]. Capstone teams are composed of four students who have self-selected the experience from a catalog of available projects. Two faculty members, the capstone course lead and a technical expert, mentor the team throughout the two-semester offering. The industry team is composed of members from engineering, technical support, and human resources. The student team organizes and leads weekly team meetings to provide status updates, pose questions, and deliberate next steps.

The engineering team at Endress+Hauser designed the platform's mechanical elements and determined the appropriate instrumentation needed to present all use cases before the launch of the capstone. When possible, the design focused on using readily available commodity components to minimize costs, reduce critical paths, and ease maintenance and repair. At the launch of the capstone, students received the entire CAD model of the initial design, the complete bill of materials, and the required materials and instruments.

Fig. 3. Process training system base design.

First Capstone Experience

The first capstone team starts by working with faculty and industry to define and clarify deliverables and the timeline for the two-semester sequence. Simultaneously, the student team familiarizes themselves with the process industry and learns more about the applications, instruments, and technologies with the assistance of the industry team through tailored presentations and on-site visits to production facilities.

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All parties participated in crafting the deliverables for the first capstone, which include

- The complete mechanical build-up and validation of the system.
    - Optional conversion from manual to electrically actuated valves.
    - Optional conversion to support the linking of multiple units.
- Design, build and test:
    - Power systems
    - Safety system
    - Operator interfaces
    - Control system
    - Compute surfaces capable of supporting system programming and future machine learning and mixed-reality applications.
    - Wired and wireless network infrastructure capable of interfacing with manufacturing network.

The deliverables require the capstone team to identify, source, and procure a wide range of components and materials to supplement those provided at the project's launch. Faculty members review the proposed solutions with the team before authorizing purchase orders to verify appropriateness and potentially identify existing resources that may be available.

The first capstone deliverable schedule has four primary stages of activity. The first stage includes preliminary project management activities, including developing deliverables, a project timeline, defining roles and responsibilities, and conducting an FMEA. The second stage focus on the buildout and validation of the mechanical system. The majority of this activity occurs in the first course. The third stage focuses on designing, building, and validating the power systems, safety systems, user interfaces, and control systems. The final phase focuses on selecting appropriate computing surfaces for the programming and operation of the training system with the capability of supporting local storage, machine learning, and mixed-reality applications to be developed in the second capstone project. In addition, the team will design and implement an internal wired and wireless network supporting connectivity to the on-site manufacturing network and mobile devices that interface with the system.

Second Capstone Experience

The second capstone team launches in January 2022 and will initially proceed down a similar path as the first capstone group. This activity includes working with faculty and industry to define deliverables and timelines while familiarizing themselves with the industry and its applications, instruments, and technologies.

The deliverables for the second capstone include:

- Development, programming, and testing of the process control system.
    - Engineering interface
    - Operator interface
    - Maintenance interface
- Connecting and testing on-premises and cloud production systems
- Connecting and testing on-premises and cloud monitoring, storage, and analytics systems
- Creating and validating introductory training scenarios

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    - Instrument technology and capability
    - P&ID
    - Loop tuning
- Developing and validating mixed reality solutions
    - Guided work instructions
        - instrument and platform orientation
        - safety training
        - maintenance procedures
    - Dashboards
        - Operation
        - Maintenance
- Creation of an introductory machine learning experience
        - Cloud-based training
        - Local deployment

The organization and management of the second capstone will mirror that of the first, with a comparable support team of faculty and industry representatives facilitating the experience.

Continuous Process System

The design, build, and validation of the continuous process system represents a challenging activity that includes exploring and implementing emerging technologies in novel configurations. This effort requires collaboration between industry teams, faculty, and third-party contractors. The scope and technical complexity of the project do not allow for a feasible student engagement opportunity in the development cycle. The high-visibility location of the system will help foster curiosity and encourage further investigation by prospective students and visitors while providing rich data streams to be used in activities in undergraduate and graduate courses.

Summary and Impact

There are no existing systems that meet the requirements of delivering an engaging learning experience with Industry 4.0 technologies in the process industry at a scope to match Purdue University's new Smart Manufacturing curriculum. It is not practical for the industry to develop an educational system, nor feasible for faculty to create a genuinely representative industrial solution. Resource and knowledge requirements are too large. A collaborative effort between industry and academia provides the best opportunity to meet the challenges of producing a learning environment capable of supporting the development of a technically skilled workforce capable of efficiently implementing the technologies of Industry 4.0.

Projects of this scale require a substantial investment of capital equipment, technical expertise, and project management support, which need a longer-term outlook to appreciate full benefits. Capstone projects provide an opportunity for early identification of talent and relationship building while improving industry visibility and establishing broad familiarization with companies, career opportunities, and technologies.

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This project will create permanent instructional platforms that will expose students from various disciplines to the devices, technologies, and applications within the process industry. The PIPES project was a first for Endress+Hauser and later generated additional university engagement with other Indiana institutions. Over six years, the system engaged undergraduate and graduate students from programs and domains including manufacturing, electrical, industrial, chemical, food science, pharmacy, and information technology. This investment has provided significant advantages in recruiting talent in a highly competitive market, with over 25% of the 75 hires into Endress+Hauser's Rotational Development program since 2014 from Purdue University.

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Biographies

Dr. GRANT RICHARDS is an assistant professor of practice at Purdue University's School of Engineering Technology. He teaches a range of courses relating to industrial IoT, process and discrete manufacturing systems, and industrial networks. Dr. Richards collaborates with domestic and global institutions and industry to develop curriculum and facilities focused on presenting new and emerging technologies in the manufacturing sector to students in engineering and technology programs.

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