Novel Approach to Bridge the Gaps of Industrial and Manufacturing Engineering Education: A Case Study of the Connected Enterprise Concepts

Wilkistar Otieno
Department of Industrial and Manufacturing Engineering
University of Wisconsin-Milwaukee, WI USA
otieno@uwm.edu

Michael Cook
Director, University Partnership Program
Rockwell Automation Inc, Milwaukee, WI USA
mcook@ra.rockwell.com

Naira Campbell-Kyureghyan
Department of Industrial and Manufacturing Engineering
University of Wisconsin-Milwaukee, WI USA
campbeln@uwm.edu

***Abstract*--The revolution caused by the advancement of technology, globalization and internet-enabled manufacturing is rapidly changing the manufacturing industry and requires engineers with different and more diverse knowledge than provided by traditionally-based curricula. In order to fill the emerging gap in engineering education we, educators, have to start thinking about preparing students for the future. This paper describes our efforts to address the 21st century workforce challenges and opportunities. We present a novel multidisciplinary education approach through a case study example from a recently implemented course. This course was part of a larger institution-wide industry-university partnership to address the education gap in industrial and manufacturing engineering programs, beginning with the Connected Enterprise Concepts (CECs). The program started with developing a multi-faceted partnership with local companies and leaders in the manufacturing industry, and cross-disciplinary collaboration between Faculty members from the University of Wisconsin-Milwaukee (UWM). We present the framework within which this course, the first of its kind, was initiated, designed and implemented. We will also provide the initial results of students' survey and propose a way to address the challenges.**

Keywords—Connected Enterprise, Engineering Education, 21st Century Workforce

I. Introduction

Traditional industrial operations relied upon stand-alone business units, paper-based communications, time-delayed data acquisition and processing and retrospective business decisions. These unconnected units and delayed business decisions resulted in increased time to market, increased production costs, loss of competitiveness and increased safety concerns. Connected Enterprise (CE) strategies are designed to address these challenges of unconnectedness by facilitating collaboration across the enterprise, and linking people, equipment and processes to enable real-time learning of the enterprise status, and adaptive decision-making.

The readiness for a company to embrace and reap the benefits of the CE and Internet of Things (IoT) lies in their willingness to overhaul or upgrade their processes, change their business models and invest in training a workforce that is ready to understand, design, implement and monitor CE strategies. The Connected Enterprise Concept is grounded on the following pillars: (1) Smart Technology, (2) Scalable Computing, (3) Cloud Access and Storage, (4) Mobility and Remote Monitoring, (5) Big Data and Cyber Security, and (6) Data Analytics. It is with these pillars in mind that the we, the authors, sought to develop and facilitate a novel course, the first if its kind in Connected Enterprises.

II. Course Syllabus

This novel Connected Enterprise Concepts course was custom-built to cover several emerging topics that were directly connected to the gaps in current industrial/ manufacturing engineering education (as a pilot course, soon to be cross-listed in other departments). A structured and integrated four stage process was used to create the curriculum for this course as follows:

Stage 1: The course planning stage consisted of a careful needs assessment and identification of gaps between the current industrial and manufacturing engineering undergraduate and graduate curricula and immediate needs in manufacturing, as well as forecasting future trends of the industry

Stage 2: The design stage involved specifying the content that would be covered in the course. Figure 1 illustrates the specific topics that were sequentially included into the syllabus. The breadth and depth of coverage required the joint efforts of seven faculty and instructors from Industrial and Manufacturing Engineering (IME), Computer Science (CS), Computer Engineering (CS), School of Business (SB), Global Economics and Policies (GEP), and over a dozen industrial experts (IND) in charge of key business units that support the Connected Enterprise Strategy in the partner company—Rockwell Automation Inc. With such a strong multi-disciplinary team we were able to leverage the disciplinary depth of knowledge of each faculty member and industry expert, with the collective breath of skills, experiences, interests and applications.

Stage 3: Having determined the key areas of coverage, the implementation stage consisted of ensuring that institutional requirements of faculty-student contact time, ABET

978-1-5090-5920-1/17/$31.00 ©2017 IEEE

accreditation requirements and outcome assessment measurements were met.

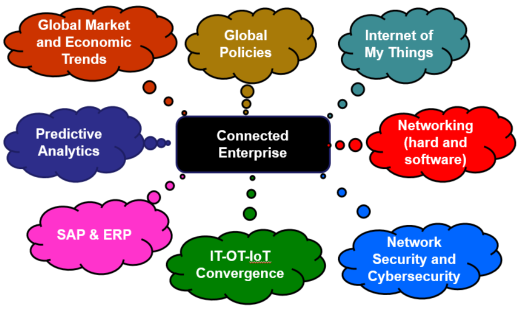

Fig. 1. Components of Course Syllabus

The course was designed to include 2 hours of lecture and 1.5 hours of lab/discussion session each week, with a rich mix of lecture-based, hands-on, on-campus, off-campus, interactive, and team-based learning sessions. Other deliberations in the implementation stage included software and tool selection, team project expectations and project selection.

Stage 4: Upon successful implementation and completion of the course a brief survey was conducted among the students to solicit feedback regarding the course content and structure. The details the questions as well as the results, which will be presented in the results discussion section of this paper. These responses were largely used in enhancing the subsequent offering of the CE course.

III. COURSE CONTENT

The development of this course was initiated and syllabus outlined following a needs assessment of the Industrial and Manufacturing Engineering curricula and the goal of educating students for the future. However, the group of seven faculty and industry experts were responsible for final refinement of the syllabus and the creation and delivery of topic-specific content for the course. In this Section, we present detailed coverage of the course focus areas.

A. Economic Globalization and Policies Advancements (Contributors: GEP, IME)

The first section of the course began with a case-study of changes that different industrial and service sectors have experienced in the last few decades, including the health, transportation, manufacturing, mining, and energy industries, most of which have transformed with innovations in information technology.

The most recent indicators of the gap between technology and policies has been the latest legal challenges with regards to data acquisition and access from ubiquitous imbeded sensor technologies. These challenges exist predominatnly because the law, and therefore ethics, has not kept in pace with technology. Following a discussion-driven lecture, the students were given a post lecture assignment, where each student picked a technology, discussed its functions, and addressed any extant policies set in place to protect consumers.

B. Industrial Internet of Things (Contributors: IME, IND)

This section of the course was a seamless transition from the first section. A few select and well done assignments from the previous section were chosen to be presented by the students in the Industry IoT discussion. Some of the highlighted technologies, most of which use the IoT as the conduit for information exchange included: (1) *Stream Analytics*, a Complex Event Processing technique that has been used by the airline and credit card industries (just to name a few) to convey real-time locational information; (2) Chicago's *WindyGrid*—a Big Data city application that integrates data including 911 and 311 service calls, public Tweets and location of public transportation network; (3) wearable devices such as *Humanyze*—a system which has the capability of providing data on worker efficiency, behavior, and interaction; (4) Computerized Maintenance Management Systems (CMMS), such as *TabWare*, that enable automatic notifications of work orders and preventative maintenance requests to maintenance technicians; and (5) *Peoplenet Fleet Manager,* an enterprise connectivity tool that was developed to address increasing accidents involving truck driver fatigue. The rest of the discussion was focused on how the IoT and cloud technology has revolutionized production, contextualized in three case companies: a mining company, a milk specialty company, and a sausage processing company.

C. Information and Cyber-Security (Contributors: CS, IND)

This discussion was led by the Chief Information Security Officer in collaboration with the Manager of Technical Security Strategy of the partner company. Students were asked to research and present on a cybersecurity issue that involved a variety of cyber-attacks. The presentations addressed the following questions: (1) What was the motivation of the attacker? (2) How did the attacker get into the victim's network? (3) What could the victim have done to protect themselves? (4) How could this type of attack be carried out in a Manufacturing/IoT environment?

D. Information Technology, Operations Technology and Internet of Things (IT-OT-IoT) Convergence (Contributors: CE, IND)

Examples of such interoperability include real-time data acquisition from equipment and enabling communication within and between industry functions. The enterprise architectures include: (1) a plant-wide Ethernet network to provide seamless communication and data streaming within the enterprise; (2) smarter plants and operations; (3) "FactoryTalk"- a software that enables real-time access to plant or process or equipment-level status to ensure real-time adaptive decisions rather than corrective interventions; and (4) intelligent monitoring and control solutions via the process augmented reality. The class also visited the customer center, and was shown examples of CE solutions that were collaboratively designed by customers and RA engineers**.**

E. SAP & ERP- (Contributors: SB, IME, IND)

Enterprise Resource Planning (ERP) systems play a crucial role in integrating transactional data, information and business processes, thereby significantly increasing firms' productivity and competitiveness [2]. Our decision to incorporate SAP, which stands for Systems Applications and Products, into the CE course stemmed from the fact that SAP is currently leading in market share compared to other competing ERP software [3]. Particularly, we based the ERP portion of the course on the ERPsim's Manufacturing Game. More details and discussion will be covered in the course project section.

F. Predictive Analytics (Contributors: IME, IND)

Predictive analytics is the use of statistical models, data mining and machine learning techniques to understand the current status of a process for predictive purposes. The syllabus included a history of data science, the renewed focus in predictive analytics, the main distinctions between predictive analytics and statistical learning, data visualization functions, supervised and unsupervised data analysis methods. For a discussion, teams of students made brief presentations of current usage of data analytics in the banking, health, climate, manufacturing, energy and the transportation sectors.

IV. COURSE STRUCTURE

Since the goal of this non-traditional pilot course was to prepare engineering graduates for current and future industries, we designed the course structure to be flexible and thus allow for adaptable learning. In addition, we made sure that the course was (i) multi-disciplinary, (ii) innovative, and (iii) interactive to allow for teamwork.

A. Intersdisciplinary

The major challenges and drivers of interdisciplinary discovery and education include: inherent system complexities, the effect of basic science on multiple applications, and the stimulus by dynamic and generative technologies such as cyberinfrastructure.

Given this background, the only prerequisite for the course was that the students needed to have senior standing. Out of 26 students in the class, 27% were undergraduate (30% female) and 73% were graduate (51% female) students. The class consisted of students from the following backgrounds: 4% Electrical Engineering, 4% Business School, 15% Biomedical Engineering, 15% Mechanical Engineering and 61% Industrial Engineering. Teams were intentionally formed for each assignment to ensure diversity across gender, disciplines, and graduate versus undergraduates.

B. Innovative

The most important concept was the use of technological advancements to improve efficiency, quality, service and many other aspects of industry. The students were able to realize that advancement of technology comes with the trade-off of requiring new skills, standards, regulations, and other areas that must be developed, requiring innovative changes and adaptations. Hence the various mix of course contents and delivery methods that are rarely covered (in combination) in one course was an innovative way of exposing students to current technological frontiers especially in manufacturing.

Our teaching methodology involved a pluralistic approach consisting of a multi-disciplinary team of instructors, as well as a mix of lecture-based, guest speaker, company visit, learning-by-doing and team-based approach of instruction. In addition, this non-traditional course required new modes of content organization, assessment methods, grading structures, and hands on experiences that recognized and rewarded each student's curiosity and self-exploration.

C. Team-Based Course Projects

A semester-long course team project was designed to engender creativity amongst students on how they would unlock the values of a connected enterprise. To do this, we first sought to understand the opportunities that companies are reaping from implementing CE strategies in their businesses. The inter-related CE implementation stages are summarized as follows:

Stage 1: Assessment and weakness identification in the existing IT/OT capabilities of the organization, including information infrastructure, data acquisition, availability and management devices and controls, as well as networks and network security.

Stage 2: Following the identification of systems weaknesses, upgrades are designed to fulfill the operational and strategic goals, with the main objective of adapting to foreseeable technological advancements.

Stage 3: To create a scope for upgrade implementation, the company defines and organizes the working data capital.

Stage 4: In the analytics stage, the firm considers system-wide changes that will enable a holistic value realization of the designed CE strategy.

Stage 5: The collaboration stage, which is the final stage in CE maturity involves a system-wide implementation of the CE strategy in the enterprise, and employs predictive analytics capabilities to increase efficiency, increase production, reduce risks, and increase safety

With the above CE maturity implementation model in mind, we designed a team-based course project that revolved around the ERPsim Manufacturing game [5,6] with the "following pedagogical objectives: (i) to develop hands-on understanding of the concepts underlying enterprise systems, (ii) to experience the benefits of enterprise integration firsthand, (iii) to develop technical skills at using an ERP system, (iv) to learn how to work in a team, and (v) to learn how to strategize in a real-time business environment [7].". For three weeks, each team mimicked a manufacturer of a fictitious cereal product to be marketed in Germany's three hypothetical geographical regions that had a set number (unbeknownst to the players) of consumers. In the end, each team presented their project performance to the class.

The main goals of the presentation were to: (1) Present the group's competition strategy—i.e. the groups' storyline; (2) Present the time-line analysis of their progress through the four runs; (3) Present the predictive data analyses models and results of each run to identify the driving factors of their company's performance and to prove or disprove whether their strategic actions resulted in the anticipated company performance improvement; (4) Identify the internal and external threats and opportunities, and (5) Identify innovative technologies that would have boosted their company's performance. The course project was evaluated based on several milestones which were set to test student's knowledge gained and the teams' ability to integrate the multiple topics learned throughout the course, as well as innovative thinking and proposal of new IoT-enabled processes that would enable seamless information gathering and assessment of market trends, inventory control, and cross-checks that would mitigate against erroneous order placements, in addition to a wide range of process management techniques that would lead to optimizing the key performance indices.

V. Course Results Discussion

The course syllabus consisted of 14 weeks during the Fall semester. Each week's class was subdivided into 2 two-hour sessions separated by a break, providing a total of 28 two-hour sessions. Of these 28 sessions, 32% involved lectures by faculty members or company guest speakers, 29% involved discussions, 14% involved hands-on learning, 18% were company visits, and 7% consisted of activities that were directly related to the course project.

To assess the overall delivery of this course, an anonymous survey was distributed via Qualtrics—an online software. Table I provides a list of questions that were included in the survey along with the average scores for each question. With 85% of response the results show that 67% and 33% of students agreed that that the course was relevant to today's graduates. The guest speakers, who provided a multi-disciplinary source of expertise, were reviewed to have been excellent (78%) and good (22%).

67% of the students rated their expected grade to be higher relative to other courses they have taken in the College of Engineering and Computer Sciences, while their rating of the course intellectual challenge was mostly higher (33%) or average (45%). In addition, though not shown in Table 1 is the university-wide course evaluation survey, where all students rank the instructor, course content, course toughness on a scale of 1 (poor) to 5 (excellent). The three average scores were: 4.21, 3.76 and 3.29 respectively.

We also solicited additional comments regarding the course that helped to reveal some additional aspects in regards to participation and the overall performance. For example, the graduate students were more knowledgeable on some topics based on their research interests and previous experience working in industry. These students helped their undergraduate teammates with the integration of the material learned in the class and the practical approach that was carried over from their experience.

As expected of a new course, the survey results showed mixed results of approval and disapproval by students, indicating that there are still a lot of improvements that would be required to increase the rating of the overall experience. Particularly, we plan to gather real CE team projects from companies, where the teams will be self-selected and each team will be given company mentors to be a source of expertise and offer guide toward the design and proposal of CE solutions for implementation.

VI. Conclussion

This paper presents a novel non-traditional interdisciplinary course on Connected Enterprise Concepts (CECs) that was created and implemented at the UWM I collaboration with industry partners. The study reveals that a successful implementation of such educational countermeasure greatly depends on careful selection of the multidisciplinary faculty/instructional team and a uniquely-identified, industry alliance to support hands-on learning experiences, and implementation assessment.

Acknowledgment

We acknowledge the contributions of all colleagues from Rockwell Automation Inc. and UWM who provided their expertise and contributed toward the success of the course.

TABLE I. COURSE SURVEY QUESTIONS AND RESULTS

Survey Question	**Excellent**	**Good**	**Average**	**Fair**
The course content was:	22%	67%	11%	
The alignment of the course objectives and the course content was:	22%	78%		
The use of class time was:	33%	56%	11%	
The instructors' availability outside of class was:	56%	33%	11%	
The guest speakers selection was:	78%	22%		
The examples used by instructors and guest speakers were:	56%	33%	11%	
The sequence of the course content presentation was:	56%	33%	6%	5%
The course material was relevant to today's graduates	67%	33%		
The assignments were manageable	45%	44%		11%
I enjoyed and benefited from the team assignments and project	45%	11%	22%	22%
Survey Question	**Much higher**	**Higher**	**Average**	**Lower**
Relative to other courses in the UWM, I expect my grades in this course to be:		67%	33%	
Relative to other courses in UWM, the intellectual challenge presented was:	11%	33%	45%	11%
Survey Question	**Best of all**	**Top 25%**	**Mid 50%**	**Worst 25%**
Overall, how does your experience in the course compare to other courses in Engineering?	33%	33%	33%	

REFERENCES

[1] Bonvillian, W., B., The New Model Innovation Agencies: An Overview, Science and Public Policy, (2014), Vol. 41, Issue 4, pp 425-437.

[2] Léger, P-M., Charland, P., Feldstein, H. D., Robert, J., Babin, G., and Lyle, D., "Business Simulation Training in Information Technology Education: Guidelines for New Approaches in IT Training", Journal of Information Technology Education, (2011) Vol 11. Pp. 39-53.

[3] SAS Global Corporate Affairs, "SAP Factsheet", (Jan 2017). [Online] Available: https://www.sap.com/documents/2016/07/0a4e1b8c-7e7c-0010-82c7-eda71af511fa.html

[4] National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, Facilitating Interdisciplinary Research. The National Academies Press, 2004, Committee on Facilitating Interdisciplinary Research, [Online] Available: http://www.nap.edu/openbook.php?record id=11153

[5] Léger, P-M., Charland, P., Feldstein, H. D., Robert, J., Babin, G., and Lyle, D., Cronan, T.P., and Charland, P., "ERP Simulation Game: A Distribution Game To Teach The Value Of Integrated Systems", Developments in Business Simulation and Experiential Learning, (2010) Vol. 37, pp 329-334.

[6] ERPsim Lab, HEC Montreal, Canada.[Online] Available: https://erpsim.hec.ca/

[7] Léger, P-M., Robert, J., Babin, G., Lyle, D., Cronan, T.P., and Charland, P., "Comparing Objective Measures and Perceptions of Cognitive Learning in an ERP Simulation Game: A Research Note", Simulation and Gaming, (2012), Vol. 43, Issue 4, pp. 461 –480.