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Meeting The Needs of Industry in Smart Manufacture – The Definition of a New Profession and a Case Study in Providing the Required Skillset

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Abstract

Industry 4.0 is the term commonly used in Europe to describe the combination of a number of emerging and rapidly evolving technologies that represent the state of the art in the Manufacturing Industry today. Going beyond simply the automation of manufacturing systems, Industry 4.0 involves the convergence of information and automation technology to create cyber-physical systems which virtualize and optimise the manufacturing process on a global scale.
The traditional unidisciplinary or multidisciplinary engineering approach has been extremely successful for the provision of Mechatronics Engineers for Industry 3.0 over the past decades. But the complexities of the cyber physical systems which must be implemented as part of Industry 4.0 require a much more comprehensive systems engineering approach. This has resulted in the requirement for the new occupation of *Equipment Systems Engineers* (ESE) who have been introduced to, and are capable of utilizing an interdisciplinary or even anti-disciplinary approach.
This paper describes the development and implementation of an Industry-Led Masters programme at the University of Limerick which was designed specifically to meet the unique skillset required for this rapidly developing field. The development of a unique Industry 4.0 teaching space is described as well as the creation of three manufacturing cells and their 'digital twins' which recreate the environment found in the field. They allow Virtual and Augmented Reality technologies to be used to interact remotely with the equipment. Close collaboration with Industry Experts is a strong feature of the design and delivery of the programme.
The teaching methods were also novel and an implementation of the CDIO method is described.
The programme recently received the award of 'Best New Masters Programme' in a field of competitors across all Irish Universities and disciplines.

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1. Introduction

This paper describes the design and implementation of a new and innovative taught Masters programme which developed for Industry 4.0 and with the specific objective of addressing a critical shortage of skills and capability in this area.

Industry 4.0 is the term used to describe the combination of a number of emerging and rapidly evolving technologies that represent the state of the art in the Manufacturing Industry today. Going beyond simply the automation of manufacturing systems, Industry 4.0 involves the convergence of information and automation technology to create cyber-physical systems which virtualize and optimise the manufacturing process on a global scale. Savari et al [1] describe Industry 4.0 as:

" ... a smart factory... [where] cyber-physical systems monitor physical processes, create a virtual copy of the physical world and make decentralized decisions. Over the Internet of Things, cyber-physical systems communicate and cooperate with each other and with humans in real time... "

A good overview of the technologies and their interactions given by Brettel et al. is shown in Figure 1.

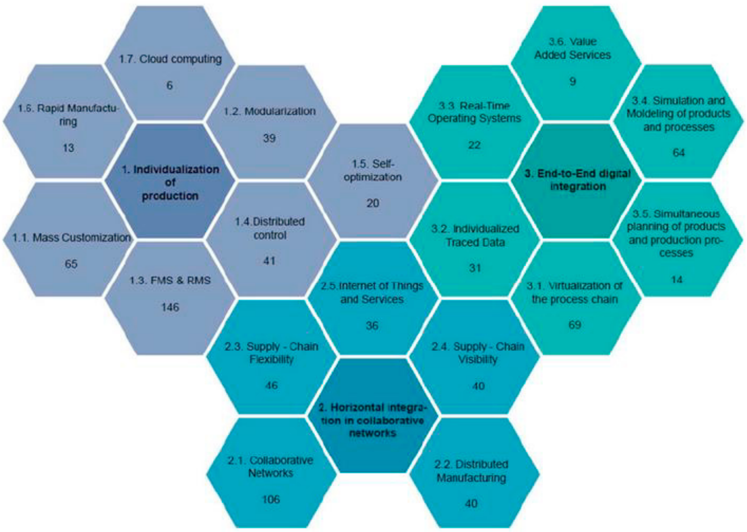

Figure 1. Technologies and Processes' for Industry 4.0 Adapted from Brettel et al [2].

1.1. Context

In Ireland Currently, the manufacturing sector employs 205,700 people directly and up to 400,000 indirectly. With the focus on employment, innovation and industry, the resurgence in manufacturing is taking a different path to previous generations. The integration of key technologies for Industry 4.0 such as artificial intelligence, the internet of things, machine learning, cloud systems, cybersecurity, and adaptive robotics causes radical changes in the business processes of organizations [3] and creates a need for expertise in this area. In Ireland, the alignment with national and economic needs has been well documented and highlighted.

1.2. Alignment with national economic needs.

Ireland's National Skills Strategy to 2025 [4] highlights skills shortages across sectors in areas of ICT, Science and Engineering that are relevant to Industry 4.0. In summary it states that: *"… the greatest skills demand is for Professionals, Associate Professionals and people with multilingual skills ". (p25).*

Interestingly it also notes that *"The management of the "tension" between stakeholders which exists for example, between the terms training and skills on the one hand and education on the other is also a critical area which requires ongoing engagement" (p21)* The shortage of talent in automated manufacture has also been well documented by professionals in the field and the need for industry to work with education providers to address this shortfall has been highlighted e.g. [5]. The same issues apply on the international scene, for example Sommer [6] describes the potential impact of a lack of preparedness for Industry 4.0 on SMEs in Germany.

1.3. Summary:

Industry 4.0 requires the integration of disparate technologies in a coherent manner. It is still an aim rather than a reality in many situations. Know how is a limiting factor in realising this aim and there is a distinct need for an improved skillset in this specific area. However meeting this need is not straightforward as traditional paths to engineering do not necessarily address this.

2. Programme Specification and Design

2.1. Challenges

There are unique challenges presented by Industry 4.0 as outlined above. The range of technologies and disciplines involved span the skillset of several professions, for example IT, Software Engineering, IoT, Automation, Business and others.

The rapid evolution of the developing technologies is driven by Industry R&D as well as the latest technologies available from equipment developers and providers.

Due to the rapid pace of development and the costs of maintaining the currency of equipment, there can be difficulty in keeping pace in providing taught programmes. Industry has often moved on by the time academia has caught up.

2.2. The importance of R&D

Therefore, to be current, the programme needs to be driven by research and R&D in particular and to have close links with both industry and equipment providers.

Pasteur's Quadrant, shown in Figure 2 is often used to describe the possible focus of different types of research.

		Considerations of Use?	
		No	**Yes**
Quest for Fundamental Understanding?	**Yes**	Pure Basic Research **Bohr**	Use-Inspired basic research **Pasteur**
	No	-------	Pure Applied Research **Edison**

Figure 2. Sources of Research Inspiration, from Stokes [7]

In the space of mechatronics where significant advancements each year is the norm, it is vital that the programme should remain current and linked to latest technological advances. While basic or curiosity research is important, the point has been made [8] that this alone cannot deliver results that can immediately be commercialised and that Use-Inspired and Applied research in the areas shown in Figure 2 are essential to innovation. Commercial R&D falls into these categories so it was essential to have a significant input and leadership from Industrial stakeholders in the programme design and specification. The aim was to deliver a programme that met the needs of the manufacturing sector for Industry 4.0. In an increasingly globalised context for manufacturing it was important to take account of multicultural and multinational aspects as well.

2.3. Meeting Needs

From the beginning, the course team set up a close working relationship with world-class players in the Smart Manufacturing sector. One leading multinational manufacturing corporation has their Research and Development facility located on campus at UL. The university also worked closely with SL Controls, a premium Equipment Systems Integration company, to design and implement the course material to best meet the needs of Industry.

This provided a platform for the development of a syllabus which is both academically rigorous and industry relevant. The outcome of the consultation was an identification of specific needs in the sector. This led to the definition of a specific skillset required of an ideal graduate. It was clear that the requirement was for *equipment systems* (taking in the broad range of disciplines involved) rather than on one subset or area. This subsequently led to the coining of the term '*Equipment Systems Engineer'* to capture the role of the professional in this discipline.

Once the role had been defined it was a straightforward task to design the programme content and pedagogy to deliver this. The programme structure is shown in Appendix A.

2.3.1. Internationalization

The manufacturing sector is increasingly globalised. In particular Industry 4.0 with its dependence on virtualisation and cyber-physical systems embodies this. It was therefore logical to build an international dimension into the programme. In parallel with the industrial consultations, a series of meetings took place with the engineering departments and international division in the Institut Mines Telecom, Lille/Douai in France to align the course structure with the needs of their year four engineering students. During discussion with the partner universities it became apparent that there was a need for a formal component on International Business Management and Project management. Expertise in this area was drawn from the UL Kemmy Business School.

2.3.2. *Defining the Future**.***

The skillset required for Industry 4.0 does not sit easily with existing engineering disciplines – A new profession of '*Equipment Systems Engineer'* was outlined as part of the process. This new profession has obtained development funding from the Irish Higher Education Authority for inclusion in its portfolio of professional apprenticeships effectively giving it official recognition as a new profession.

2.4. Programme Implementation and Delivery

The aim was to provide a closely integrated programme where theoretical aspects and practical applications were closely aligned. This was made possible by the sharing of decades of industry developed expertise and knowledge with the programme. This close collaboration has attracted significant interest and support from other stakeholders, resulting in the extensive resourcing of the programme with equipment and software from number of companies and vendors in the manufacturing sector who perceived the commercial value of being involved in a programme with such close ties to their customers. In order to provide the infrastructure required to deliver the course, a state of the art purpose built Industry 4.0 facility was developed on campus which combined a teaching space with laboratory and workshop facilities. The cooperation of the equipment providers significantly enhanced the facility and were and a critical enabling factor in its success.

2.4.1. Delivery: The student Experience

It was intended to provide as authentic an experience as possible to the students which would accurately reflect the issues they would encounter in their future roles in industry. At the same time, the students should receive a sound academic grounding in the knowledge and practice required. To deliver this, the CDIO principles were used as a model for the pedagogy of the programme.

Conceive Develop Implement Operate (CDIO) (www.cdio.org), is an engineering education philosophy originally developed by MIT and adopted by universities worldwide. CDIO involves an immersion of the student in the complete lifecycle of the article being designed, from design, to build, operation and end of life. To achieve this, the programme involves extensive hands-on practical work which is closely related to theory and comprises a mix of theoretical and practical elements. The students work on projects as teams with predefined roles in the same way as they would in industry. The first two semesters concentrate on building up the basic knowledge and theory required and involves some short projects that foster team building.

The programme culminates in a capstone project which is the sole focus of Semester three and which spans the two previous semesters. The students are organised into groups at the start, where each member has a specific role. The execution of the project closely reflects the reality of industry. In semester One the students encounter the design and automation standards ISA-88 and ISA-95 and use these to *design the design process*. In semester two they execute the design process itself according to the criterial set out in semester 1. In semester three they build and test the system. The process is documented as a series of technical papers which are critiqued by industry and academic experts before publication as a book. In parallel the modules on Project Management and International Business Management provide a multicultural and multinational commercial backdrop to the technical aspects.

Overall, and in keeping with the thinking behind Industry 4.0 a variety of innovative pedagogical approaches are used:

- A wide mix of delivery mechanisms, (Skype, E-modules, Flipped Classroom, CDIO Projects, Distance Learning)
- Targeting leading industrial experts to deliver modules and oversee projects.
- Flexible scheduling to facilitate contribution from industry experts but also to facilitate students in employment to study on the programme.
- A team project where individual contributions recorded digitally.
- The Team project is scaffolded by a high level of expert input from industry. The CDIO approach involves a high level of experiential learning and hands-on activity. Throughout, the students' work as teams as they would in real life.

3. Results:

A detailed survey of similar programmes reveals no other taught masters programme in Europe that provides the same level of relevance or technical content. The programme is now in its second year running and has attracted significant interest from students both at home and abroad. The present cohort is 30% Irish, 30%EU and 40% Non EU students. Eight students took the programme in 2016 and sixteen in 2017 with a projected 20 intake in 2018.

The programme requires 20 contact and 20 independent hours of work per week and runs over three fifteen week semesters. The programme is delivered by a combination of four faculty members and two industry specialists.

In semester one the students are assessed by formal written examinations in 20% of the programme and 80% by the completion of practical projects and reports. This is appropriate to the learning outcomes for this semester. In semester 2 the assessment is 50% examination and 50% practical coursework as the focus changes. The third semester is assessed entirely through the project output which comprises a build and written element. Each student has a different facet of the task as their responsibility as described earlier. As well as their contribution to the system design and build, they are required to write a technical publication comprising a chapter from each student on their own specialism, which acts as the written component of their assessment. This publication is reviewed by industry specialists and academics within the University of Limerick. The first of these is being published in book form and is currently in press.

3.1. Student Output.

The exchange of knowledge between Industry and the programme made possible the development of three Industry 4.0 manufacturing cells as the capstone project, using the same technologies employed by industry R&D. They are unique in a programme of this kind and represent the state of the art. For each cell, a Digital Twin has been developed which emulates the physical system. It is possible to interact with the cells using Virtual and Augmented Reality, remotely over a computer network. One of the cells and its digital twin are shown in Figure 3 below

Figure 3 (a) Physical Manufacturing Cell and (b) Virtual Digital Twin

Each cell is a Rubik Cube manipulator incorporating a Vision system and 8 axes of motion.
The advantages of this approach is there are no consumables or waste, a batch size of one is possible (each cube configuration is unique) and the machines can run continuously, offering the possibility of capturing performance data over an extended period and performing analytics on it, thus providing a novel insight into the process. Each machine contains a sensing element, signal conditioning, signal processing and is connected to a network.
The Sensing Element is the actuator controller which allows measurement of axis position.
The Signal Conditioning is performed by a Programme Automated Controller (PAC) which provides data for an ISA-S88 physical and procedural model. A Calculus Add On Instruction (AOI) processes the measured variable, creating derived variables and structures the data for logging. The system is networked for the transfer of information from the PAC to a Microsoft SQL Server. The overall system architecture is shown in Figure 4 below.

The systems were geometrically modelled in SolidWorks, and kinematically modelled using Emulate3D and Rockwell PACs. A Microsoft Hololens was used for the Virtual/Augmented Reality capabilities. Cognex Vision systems were used and a Factory Talk transaction manager was employed to manage the communication between the elements of the system. A Knowledge Management strategy was developed for the deployment of the sub systems and to capture the tacit knowledge that frequently exists in an enterprise but is elusive to the independent learner.
Each student took a different aspect of the system as a specialism, for example, Emulation, and developed their knowledge to a high level in this area while being knowledgeable on the other aspects also.

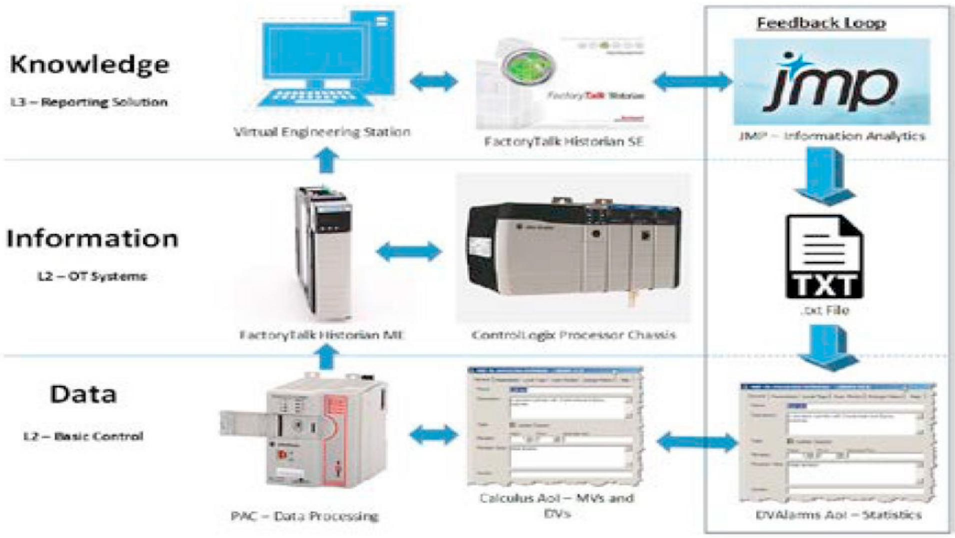

Figure 4 System Architecture.

This has pushed the boundary of what is possible. Students learn from the best, develop an understanding of key technologies, pushing them to and beyond their perceived capabilities. Industry in turn benefits by obtaining this feedback in a facility which can simulate and optimise their automated manufacturing systems without risking product or disappointing customers.

4. Discussion:

4.1. Knowledge Sharing and benefit for Industry.

The knowledge generated by the students is fed back into industry through the Technical Papers written by the students. These papers were circulated to leading team of industrialists from companies such as Unilever, where the papers are critically evaluated for technical content. During this process the knowledge contained is imparted to industry to give a detailed analysis of the capability of the technology. After review, the papers are compiled and published as a peer-reviewed publication which is recognised by ISI. In this way the knowledge generated is shared with both Academic and Industrial communities.

The programme has provided the opportunity for the industry partners to develop new techniques and equipment. For example one of the Industry 4.0 manufacturing cells developed by the students is being redeployed by one industry partner in their R&D division as a benchmark for further development. During the past months they have used it to prove the concept of a 'Digital Twin' using Virtual Reality technologies as described above.

The graduates themselves take the knowledge with them into the workplace. This is a significant output of the programme and not to be overlooked.

4.2. Feedback:

The programme graduated its first cohort of students in January 2018, all of whom went directly into employment in the sector.

The programme received an award from GradIreland, [8] as the best new taught masters programme in Ireland in November 2017**.**

Gradireland is a partnership between the Association of Higher Education Career Services (AHECS) and Group GTI, the world's largest graduate careers publishing company.

5. Conclusions.

1. The M.Eng. (Mechatronics) was set up as an internationally focussed programme intended to address the strategic needs of the Irish and international manufacturing sector in relation to Industry 4.0 It has been successful in this aim.
2. A Key enabling factor in this was the early and complete involvement of the industry stakeholders and experts in the design and implementation of the programme.
3. Industry involvement made access possible to resources and equipment that would otherwise been unobtainable.

Appendix A. Programme Structure

Autumn Semester	Spring Semester	Summer
Core	**Core**	• Mechatronics Project 2
Low Cost Automated Systems	• Mechatronics Project 1	
Automated System Design	• Digital Control	
Project Management in Practice	• Global Business Strategy	
Path A - Automation	• Machine Vision	
	Path A – Automation	
Advanced & Emerging Manufacturing Technologies		
Automation and Control	• 3D CAD Modelling & Machine Design	
	• System Integration	
Path B – Software and Control	**Path B – Software and Control**	
Computer Networks 1	• Web-based Application Design	
C++ Programming	• Real-Time Systems	

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