Industry 4.0 as an Enabler for Sustainable Manufacturing: An Educational Perspective

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Abstract

The chemical engineering sector faces the challenge of meeting the continuously growing demand for their products and services while at the same time ensuring that the industry fully integrates the concepts of sustainable manufacturing. Industry 4.0 provides immense opportunities for the realisation of sustainable manufacturing.

Industry 4.0 is a concept that represents the adoption of techniques and processes by industry to gain competitive advantages in domestic and global markets, and Pharma 4.0 is an iteration of Industry 4.0 that relates specifically to the pharmaceutical and biopharmaceutical sectors. The emerging technologies encountered in Pharma and Industry 4.0 facilitate sustainable value creation, through the implementation of agile and smart technologies leading to highly efficient automated processes driven by an integrated manufacturing control strategy.

The objective of this research is to quantify the industrial opportunities for enhanced sustainable manufacturing and in parallel evaluate the status of Industry 4.0 within 3rd level chemical engineering education and training establishments such as the National Institute for Bioprocessing Research and Training (NIBRT).

The research focuses on cross-linking, as well as the implementation of Industry 4.0 with curriculum development and examines critical aspects of industrial application such as production efficiencies, eco-friendly production, and end-of-life products disposal, providing new educational sustainability benchmarks.

Preliminary findings indicate that students have fundamental knowledge regarding core Pharma 4.0 concepts such as Augmented Reality, Cloud Computing and Artificial Intelligence; however, the structure of the 3rd level engineering education needs to adapt, incorporating a more connected curriculum in order to ensure new graduates can successfully engage with a rapidly developing industry and related Pharma 4.0 concepts. Similarly, training institutes indicate an increasing requirement to re-train staff associated with pharmaceutical and biopharmaceutical industries, to upskill 4.0 concepts among the existing workforce.

Keywords: Engineering Education; Employee Training; Industry 4.0; Pharma 4.0; 4th Industrial Revolution; Survey

1 Introduction

Industry 4.0 is a concept which is geared towards increasingly individualised customer requirements and leverages developments in process automation and data analysis, including cyber-physical systems (CPS), the internet of things (IoT), industrial internet of things (IIOT), cloud computing, cognitive computing and artificial intelligence to optimise all aspects of processing over the entire value chain of the life cycle of products, according to research by (Vaidya, et al., 2018). Engineering education traditionally focused on the theoretical fundamentals while sustainability inherently relies on optimised processes and products. This paper presents a clear and rational roadmap for curriculum development which exploits the advances of Industry 4.0 as applied to enhanced sustainable production, digital maturity, and data integrity by design.

Achieving sustainability in manufacturing requires a holistic view spanning not just the product, and the manufacturing processes involved in its fabrication, but also the entire supply chain, including the manufacturing systems across multiple product life-cycles. There is now a well-recognised need for achieving overall sustainability in industrial activities, arising due to several established and emerging causes: diminishing non-renewable resources, stricter regulations related to environment and occupational safety/health, increasing consumer preference for environmentally-friendly products, etc. (Jayal & Badurdeen, 2010)

Although there is no universally accepted definition for the term “sustainable manufacturing,” numerous efforts have been made in the recent past, with much more concurrent efforts well underway. The U.S. Department of Commerce defines sustainable manufacturing as: “*The creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound*.” (ITA, 2012)

Chemical Engineering (CE) is a versatile discipline, both in education and employment. The taught curriculum is varied, offering problem solving, design, control, management, materials science, safety, economics and environmental impact, in tandem with CE fundamentals, which all prepare students for a range of roles within industry and research. (J.Fletcher, et al., 2017). In recent times many engineering departments around the world have modified their curricula to cater for the increasing importance of environmental and social concerns in the wider community. This research seeks to expand on educational development and in embedding 4.0 in education, a critical technological enabler with sustainability. Chemical engineering continues to evolve rapidly as a profession. It is essential that new graduates have the skills to perform in an ever-wider variety of roles and industries. (IChemE, 2019).

2 Investigating the Current State

For industry to continue developing technologically, a suitably skilled graduate supply chain is essential. Obligation rests with Universities and Training Institutes to ensure graduates are up to date with technology changes. Third level education and training needs to provide students with resources and exercises which mimic industry technologies and practices. The skills gaps across all industries are growing at an unprecedented rate, which is due to the snowballing deployment of advanced digital technologies, rapid advances in AI, and IIoT integration across various industries (Ghobakhloo, 2020). Research by (Rampasso & Anholon, 2019) identifies a growing need for universities to prepare their undergraduate students to work towards sustainable development, and identifies factors that hamper the implementation of an Education for Sustainable Development the transdisciplinary character of sustainability and the excessive focus on environmental issues to the detriment of economic and social issues. Thus, it is evident in the literature that there are many challenges to be overcome by higher education institutions to achieve an Education for Sustainable Development. (Guerra, 2017) (Balsiger, 2015)

The current state of 4.0 in Chemical Engineering education as well as the pharmaceutical and biopharmaceutical sectors was investigated using a range of surveys. Questions were structured to encourage the respondent to express their professional opinion through open-ended questions as well as specialised formats. One such format is the Likert scale. This style of question is typically used to represent attitude towards a topic. To focus the survey responses according to (Binggeli, et al., 2018), multiple choice questions were used where possible and open-ended questions were limited to short responses. Research by (Saleh & Bista, 2017) examines the impacts of online survey response rates in educational research. The survey results were analysed using a combination of Microsoft Forms and Excel analysis.

2.1 The Current State of Industry 4.0 and Sustainability in Education

Current Chemical Engineering third level students contributed to the initial survey, spanning several year groups (2nd, 3rd, 4th, and Masters) and universities across Ireland (UCC 51%, CIT 22%, UCD 16% and QUB 11%). The principal of this research was to assess the level of 4.0 knowledge among students. The major aims of this survey were to:

- Establish understanding of basic 4.0 concepts such as cloud computing, AR, VR, AI, data integrity by design, smart manufacturing and smart products.
- Establish the suitability of the curriculum to prepare students for the future workplace.

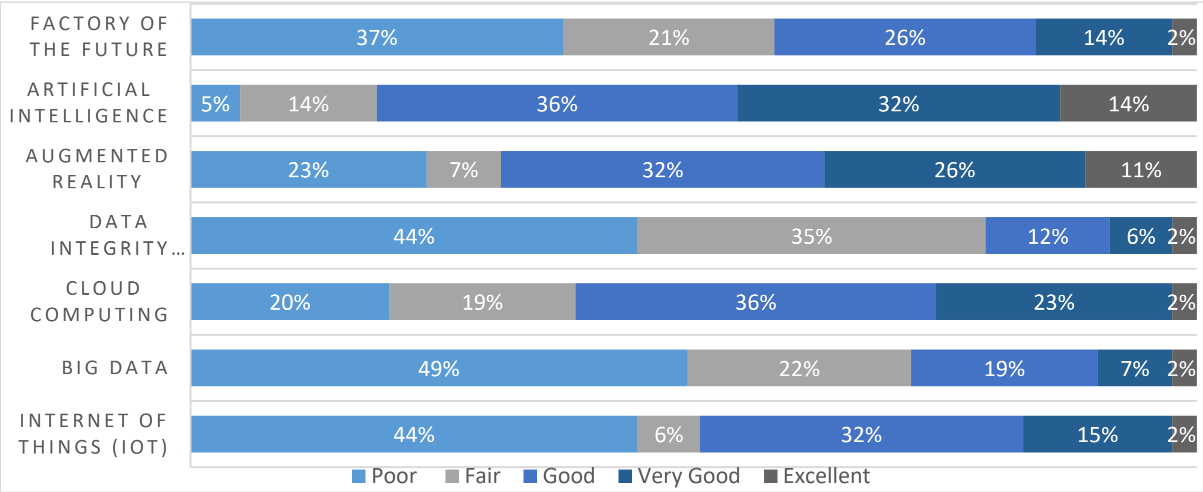

Figure 1- 3rd level student responses indicating knowledge of Pharma 4.0 key concepts (n=81).

Findings indicate that 74% of students – out of a total response pool of 81 – have no knowledge regarding Pharma 4.0 concepts. Of the students who indicated knowledge of Pharma 4.0 (26%) expressed knowledge of Augmented Reality, Cloud Computing and Artificial Intelligence. Figure 1 shows that key Pharma 4.0 concepts such as Big Data, Factory of the Future and Data integrity by Design are not widely known, however, more cross functional concepts such as Augmented Reality and Artificial Intelligence were recognised by a larger number of students. 65%, or 53, of the students questioned indicated that Pharma 4.0 concepts aren't covered as part of their degree. This raises the question of the suitability and modernity of module content. Of the 35% of students which had indicated 4.0 related modules were a part of their university degree, the major topics covered were Augmented Reality, Virtual Reality, Internet of Things, Artificial Intelligence as well as the implementation of continuous bioprocessing and continuous improvement systems.

While the technology behind the revolution has been advancing, the education amongst the current generation of workers has not been developed to match the requirements of industry. This has led to a knowledge gap between the skills of students joining the workforce and the skills they require to thrive in a 4.0 environment. This was evident in the survey results with 14% of all student respondents indicating exposure to Pharma 4.0 during their work placement but limited to no mention of 4.0 during their time in university, with only 26% having heard of 4.0 before.

From the survey, it was clear that students had not been exposed to Pharma 4.0 as a complete topic; however, individual aspects such as AR & VR, cloud computing, artificial intelligence and cyber systems, were more easily recognised by the respondents. At present students do not have the required skills to apply their fundamental engineering within a 4.0 context.

The survey indicates that technological developments achieved in industry in 4.0 and in its application to sustainability require changes to the current education model. Curriculum change will ensure students will successfully implement and realise the full potential of 4.0.

2.2 The Current State of Industry 4.0 and Sustainability in Industry

A further survey conducted with industry highlight the development of 4.0 in the pharmaceutical sector. Although only 42% of the 78 respondents indicated knowledge of 4.0, the majority of those (70%) identified as Vice-President, Director or Manager. Likewise, when departments within the company were examined, it was found that the bulk of respondents which indicated a knowledge of 4.0 identified with either the Automation or Engineering department. A similar trend was seen with regards to experience level – respondents with more than 8 years of experience were more likely to have knowledge of 4.0, with 82% of the responses. This indicates both the lack of a younger workforce presence in higher management positions and the lack of 4.0 knowledge among younger respondents.

The principal areas of focus with regards to 4.0 adoption which would affect key skills required by graduates are identified in Figure 2. Optimisation is the clear leader and this work will further show that industry are utilising this optimisation opportunity to fully explore the boundaries of implementing sustainability goals.

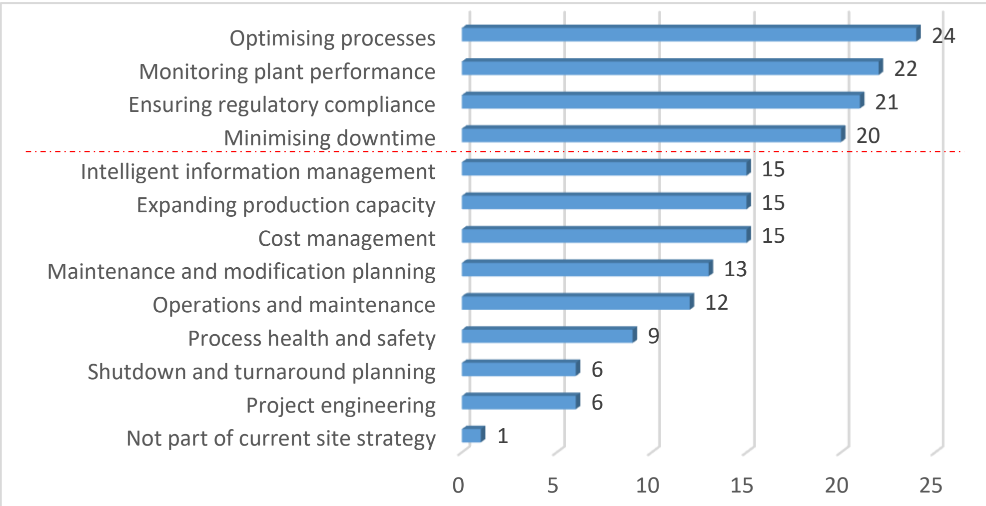

Figure 2 - Principal areas of 4.0 focus, top areas demarcated, n=179.

3 How is 4.0 framing the implementation of Sustainability

Optimisation projects currently being implemented by J&J Ringaskiddy Cork gives an insight into how 4.0 is influencing overall modern manufacturing strategies with respect to sustainability. The ability to access key process data and metrics 24/7 is generating significant opportunities with respect to achieving enhanced sustainability goals. Two 4.0 technologies/sustainability project areas are in operation.

- Project Cold Chiller Optimisation
- Project enAIR HVAC Optimisation

3.1 *Project Cold*

The conversion of an all-variable speed, water-cooled chiller plant powered by OptimumLOOP™. With the goal to increase COP (coefficient of performance), reduce site carbon footprint and operational spending. To date energy efficiency increases of 60% have been achieved through the use of OptimumLOOP™ a patented, state-of-the-art software that provides continuous, system-level optimisation of the centrifugal chiller. The control algorithms automatically calculate the most efficient operation of the chilled water system to minimise total system coefficient of performance (COP). This system is enhanced with the inclusion of OptimumMVM™, a web-based measurement, verification, and management software-as-a-service (SaaS) platform incorporating OptimumMVM, which acts as a continuous feedback loop that provides detailed, real-time, and historical performance information. The system enables operators to quickly detect, diagnose, and resolve system faults as they occur. Additionally, it provides 24/7 access to efficiency performance metrics critical to benchmarking and maintaining efficient operation year after year.

Project Goals and metrics

The savings associated with this project were 914,293 kWh and 1,586 m^3 of water per year, giving an annual CO_2 reduction of 489,451 kg/year.

Table 1 - Monthly savings included in terms of $ savings and COP data for 2019.

Timestamp	Dollars Saved (Currency)	Actual kW/Ton (COP)	Old kW/Ton (COP)	Project kW/Ton (COP)
02/01/2019 00:00	9377.85	7.40	3.82	6.06
03/01/2019 00:00	8027.53	5.99	3.82	5.92
04/01/2019 00:00	8492.31	6.30	3.86	5.89
05/01/2019 00:00	9872.99	6.55	4.08	5.76
06/01/2019 00:00	12674.47	6.36	4.13	5.40
07/01/2019 00:00	20086.90	6.34	4.03	5.06
08/01/2019 00:00	14632.67	5.99	4.12	5.28
09/01/2019 00:00	13161.72	6.28	4.17	5.42
10/01/2019 00:00	13330.07	7.24	4.21	5.62
11/01/2019 00:00	14538.03	8.51	4.23	5.66
12/01/2019 00:00	14424.65	8.38	4.22	5.69
01/01/2020 00:00	13841.76	8.42	4.21	5.73
02/01/2020 00:00	4796.70	8.81	4.24	5.68
	157257.63			

3.2 *Project enAIR (HVAC optimisation)*

This Heating Ventilation and Air Conditioning (HVAC) project utilised Optimum's holistic optimisation platform design to delivers continuous real time data collection (RTDC) year after year with minimum effort. Optimum deploys software within the HVAC system via a networked application that acts as a gateway between the building automation systems (BAS) and the cloud-based management platform. This holistic approach to HVAC optimisation lays the framework for keeping the central plant operating at maximum efficiency. The control strategy utilises OptimumAIR is patented, state-of-the-art configurable software that provides continuous, system-level optimization of air handlers. Its relational control algorithms automatically calculate the most efficient operation of the air handlers to minimise total system energy use.

Project Goals and metrics

The benefits of implementing Project enAIR:

1. Increasing HVAC system efficiency
2. Cutting energy consumption
3. Lowering carbon emissions
4. Understanding the operational issues currently impacting energy and financial savings goals
5. Developing an optimisation project plan and budget

4 The Engineering Degree - Evolving to 4.0/Sustainability

This research identifies two fundamental concepts:

1. The impact 4.0 is having across all areas of manufacturing
2. Sustainability increasingly relies on enabling technologies such as 4.0.

Engineering education has adapted relatively successfully to incorporate sustainability as an essential curriculum constituent. To enable the chemical engineers of the future to fulfil their role in society, accreditation processes must enable and promote sustainability as a core operating principle (Mitchell, 2000). As evidenced by the examples highlighted, meaningful sustainability makes extensive use of enabling technologies such as 4.0. The key to success is to integrate education with the ongoing advancements in industry. The pedagogical question arises, it possible to create a learning space that promotes connection and collaboration with industry at the same time as enhancing the student learning experience through technology and 4.0? The site wide savings for J&J Ringaskiddy shown in Figure 4 give an insight into how academic design exercises should incorporate real world metrics.

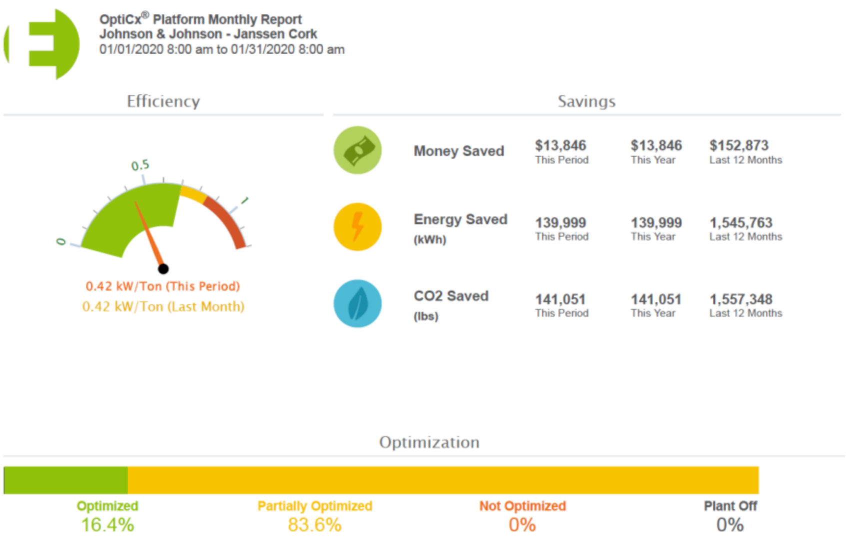

Figure 3 - J&J optimisation graphics.

Systemic design evaluation, incorporating the metrics of money, energy and CO_2 will promote the development of critical thinking skills helping students to understand the real complexity of sustainability issues and provide the competence to move beyond the tradition of breaking problems down to disconnected parts. (Conlon & Nicolaou, 2013). In Chemical engineering we call these disconnected parts "Unit Operations" which remains the fundamental way of teaching students. Industry has moved to an integrated system approach many years ago, and the advent of 4.0 as a powerful integrating force has greatly accelerated this process. Shifting from the traditional teaching to a framework of Education 4.0 requires the interweaving of traditional unit operations combined with 4.0 enabling technologies that take a systems wide sustainability approach.

5 Educational Perspective 4.0/Sustainability

This research examines the Educational Perspective of Industry 4.0 as an enabler for sustainable manufacturing. The case studies from J&J Ringaskiddy, Cork highlight an industry increasingly utilising enhanced technology to drive sustainability goals; no longer relying on seismic sifts in design or operational applications such as green chemistry or process intensification, but rather by utilising the power of data driven incremental improvements across every aspect of production. Engineering education can also adopt this approach. Degree structure is currently structured with modules and semesterisation, however these present an inherently disconnected model. When asked to comment on this disconnect one student noted: *"Most concepts are unique to the modules we come across them in. I feel like we learn the material for the exam and promptly forget it again".*

This research proposes to challenge this disconnect by the use of identical and repeated "learning outcomes" across modules and semesters, and a possible concept is outlined here.

Learning Outcome: Evaluate the role of 4.0 technologies as a powerful enabler towards greater sustainability

- PE1003 Introduction to Process & Chemical Engineering
    - **Recycling Materials (glass, metal, plastic, wood, mixed packaging)**
- PE2011 Process Plant Design & Commissioning
    - **Chiller Example (Laboratory COP)**
- PE3009 Pharmaceutical Engineering
    - **HVAC Example (Clean Room Case Study)**
- PE4001 Process Design & Feasibility Analysis
    - **Heat Exchange Networks (WFI heat recovery)**

6 Conclusion

This paper has presented 4.0 technologies as enabling industry to implement systematic, holistic sustainability goals. The sustainability and 4.0 case studies from J&J Ringaskiddy Cork for a chiller plant and HVAC optimisation were outlined. Research into the current state of 4.0 in education and industry identifies that 4.0 is becoming an exceptionally powerful force for change. However, while industry is progressing at an exponential pace – and incorporating the available 4.0 technologies – the knowledge gap between education and working life for graduates is widening. The ever-increasing importance of sustainability is established, but the context of 4.0 has shifted the focus from singular isolated gains, to incremental improvements across all systems utilising high levels of data visibility.

The J&J sustainability case studies illustrate the profound effect 4.0 is having in relation to industrial advances in terms of overall process efficiency. These examples are then retrofitted across a range of modules and years of engineering education, detailing how pedagogy can redevelop curriculum to integrate sustainability within the context of the powerful enabling technologies, namely Industry 4.0.

A proposed shift with respect to learning outcomes for engineering education is outlined, to allow for a through line approach to the degree, linking together modules and semesters by adopting "doppelganger" learning outcomes with 4.0 concepts and sustainability at the core. The learning outcomes specifically lean on 4.0 as the enabling technology and utilise real world examples provided by industry partners such as J&J Ringaskiddy Cork. Industry 4.0 is an enabler for sustainability goals, and the role of education is to empower the future workforce, both with regards to technology and sustainability among others. The risk for engineering education is very stark, considering the speed at which industry is adopting 4.0 and the vast connected world of optimisation possibilities it generates. The graduate of the future is entering a connected world, they need a connected curriculum.

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