A Trans-National Smart Manufacturing Education Hub

Intellectual Outcome 5

Market Research Report for Industry 4.0 Related Undergraduate, Postgraduate and Training Programmes

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1. Introduction

In Northern Ireland, where the project coordinator, Queen's University Belfast is located, Manufacturing is a cornerstone of the economy with the sector sustaining one quarter of all jobs in the region. It directly contributes more than 85,000 jobs (10% of employment) and accounts for two thirds of Northern Ireland's exports (c£7bn) whilst contributing 14% of the region's GDP. In the Republic of Ireland, where manufacturing accounts for 22% of their GDP, manufacturing employs approximately 0.5 million people either directly or indirectly. Ireland is particularly strong in high value manufacturing sectors and is currently the 7th largest exporter of medicinal and pharmaceutical products in the world.

As industry embraces digitalisation technologies to meet the demands of consumers with regard to mass customisation, quality and cost, while at the same time delivering economically, environmentally and socially sustainable manufacturing into the future, it needs to have recourse to a versatile and digitally skilled work force. The skills gap in this regard is a major barrier for many companies and is a recognised constraint on economic growth and competitiveness of the manufacturing sectors in the partner institution countries, and across Europe more generally. See for example, UK Made Smarter Review[1], the Northern Ireland Economy 2030 report[2], Ireland's Industry 4.0 Strategy 2020-2025[3] and Greece's Digital Skills for Digital Greece Action Plan 2019[4]. Some of the most relevant areas to develop advanced manufacturing to further the above agenda includes mechatronic and robotics in the context of Industry 4.0.

As stated by the "Global Mechatronics and Robotics Courses Market" report by Market Research Future, the Mechatronics and Robotics market is growing at a faster pace with substantial growth rates over the last few years. It is also projected that the market will grow significantly in the forecasted period i.e. 2021 to 2023. A compound annual growth rate (CAGR) of approximately 15% is estimated, as depicted in Figure 1 reaching USD 15 Billion by 2023.

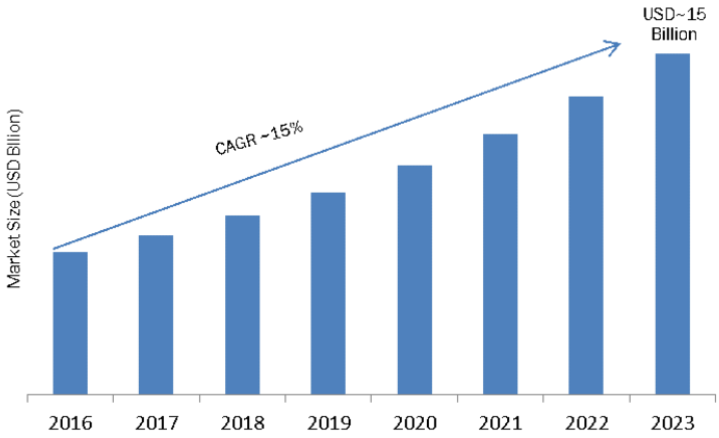


Figure 1. Mechatronics and Robotics Courses market[5]

For the reader's benefit, a brief overview of the evolution of industrial revolutions is provided in the following from fully mechanical plants to fully networked cyber physical systems.

[1] https://www.madesmarter.uk/made-smarter-review
[2] https://www.economy-ni.gov.uk/consultations/industrial-strategy
[3] https://dbei.gov.ie/en/Publications/Irelands-Industry-4-Strategy-2020-2025.html
[4] https://www.nationalcoalition.gov.gr/wp-content/uploads/2019/06/NC-Action-Plan-2019_EN-v5_272178237_signed.pdf
[5] https://www.marketresearchfuture.com/reports/mechatronics-robotics-courses-market-5689

1.1 Industrial Revolutions – A Brief Overview

The manufacturing industry has endured four industrial revolutions over the last few hundred years. A brief outline is presented below:

Industry 1.0

The First Industrial revolution in the late 18th century introduced mechanical production to the world. Steam power and water powered machines were designed and implemented to help workers on the mass production of food, textile and various other materials. Innovations such as the weaving loom which transformed mass manufacturing of goods can be thought of as the beginning of industry and manufacturing as is known today.

Industry 2.0

The Second industrial revolution at the start of the 20th century began to revolutionize manufacturing with the advent of electricity. Electrical energy was soon employed as the optimum way of powering machinery compared to water and steam power. The first assembly line was implemented due to the advancement of electrically powered conveyor belts and machinery, familiar to most as Henry Ford's model-T production lines.

Industry 3.0

The end of the 20th century saw advancements in the electronics and computing industry, with the innovation of advanced electronic devices. Machines and procedures that relied on manual operation could be automated, allowing increased speed, accuracy, repeatability, and reduced downtime.

PLC's (Programmable Logic Controllers) developed automation more than ever before, while the implementation of CNC plant and machinery meant that parts could be manufactured with reduced cycle times and increased accuracy. With considerable advancements in computing and communication technology throughout the 1970's, 80's and 90's, the manufacturing industry began to read, record, compare and historize data directly from the production floor enabling improved enterprise resource planning (ERP), tracking of unscheduled downtime and improved maintenance response.

Industry 4.0

The Internet boom of the 1990's changed communication across the globe and was considered the early beginning of the fourth industrial revolution. During the late 90s, Kevin Ashton first coined the term "Internet of Things" while working to optimise supply chains at Procter & Gamble using RFID. The ongoing COVID-19 crisis of 2020 highlighted the extent of our reliance on the internet for communication, data collection and metrics analysis.

The vision of Industry 4.0 became public knowledge for the first time in 2011 at the Hanover Messe (Annual German Industrial Technology Fair). Subsequently one year later, the Industrie 4.0 working group (part of the Research Alliance's Communication Promoters Group) presented their recommendations for implementation to the German Government in October 2012 and their final report was submitted to the German Government at the Hanover Messe in 2013. During this time three German industry associations (Bitkom - Germany's digital association, VDMA - Germany's mechanical engineering association & ZVEI - Germany's Electrical/Electronic manufacturers association) had set up the Industrie 4.0 platform coordinating activities in this area. It is worthy of mentioning that the same three associations were also responsible for the standardisation of PLC communication protocols such as PROFIBUS and PROFINET in the 1980s & 1990s.

The OPC Foundation (Open Platform for Communication) also play a pivotal role in M2M (Machine to Machine Communication) with OPC-UA (Unified Architecture) paving the way towards a multi equipment vendor data sharing protocol.

Industry 4.0 is the next evolution in technology to further automate and digitally transform the manufacturing industry by enabling machines and equipment to access, gather and visualise more data. The data is then utilised to reconfigure product output, reduce individual product batch size and provide manufacturing enterprises with access to "End-to-End" data seamlessly from CRM (Customer Relationship Management) to real time shop floor production data to raw material procurement, warehouse inventory and management using machine learning and artificial intelligence to aid human workforces to make more informed "decisions" based on data analysis of live and historical production trends. This helps to free up humans to concentrate on complex tasks that require innovation and creativity, tasks that robotics and AI cannot perform. An overview of the Industrial evolution is depicted in Figure 2.

Industry 4.0 can be thought of as a complete paperless data "closed Loop" feedback system from the start of an operation to the end of an operation. The concept of a "Digital Data Twin" is used to retain harvested data from real world cyber physical systems making it seamlessly accessible and visible to all IT and OT sub systems in real time within a manufacturing enterprise or across multiple enterprises.

1.2 About the Smart-Edu4.0 Project

The Smart-Edu4.0 project is an European project funded under the Erasmus+ programme on establishing 'Strategic Partnership Projects for Higher Education' (KA203). The project aims to establish a *Trans-National Smart Manufacturing Education Hub* focusing on advancing Industry 4.0 educational activities at and across all institutions involved in the programme. This will be achieved through the design of industry-attuned and accredited new curricula and adaptation of existing curricula for undergraduate, postgraduate, and continuous professional development (CPD) training programmes, and the development of bespoke CPD leadership programmes to support Industry 4.0 champions within companies. The Hub will function both remotely and within each institution through exploitation of online meeting and teaching tools, as well as international exchange of students and academics. Embedding the two core concepts of Industry 4.0, namely Cyber-Physical Systems and Internet of Things, Smart-Edu4.0 will enable all stakeholders to visualise and develop the necessary skillset to work in the smart factory of the future, with a focus on efficiency, productivity, customisation and sustainability.

The key objectives of Smart-Edu4.0 are centred around Industry 4.0 driven international mobility, a partnership in international curriculum delivery, research collaborations on industrially motivated new design solutions and skills development in industry including industry 4.0 leadership. Specifically, the project will have the following objectives:

1. Development of a new international curriculum model in the area of *Mechatronics* for manufacturing.
2. Introduction of new degree pathways for fresh industry entrants that are fit for the highly skilled workforce of the future with direct input from global manufacturing knowledge.
3. Design of new training pathways for the current low skilled manufacturing workforce in each Programme Country bringing them up to at least the minimum standard required to enable them to compete in this rapidly advancing industry. This will include a mix of apprenticeship training programmes as well as new undergraduate and graduate degree programmes to upskill the existing workforce.

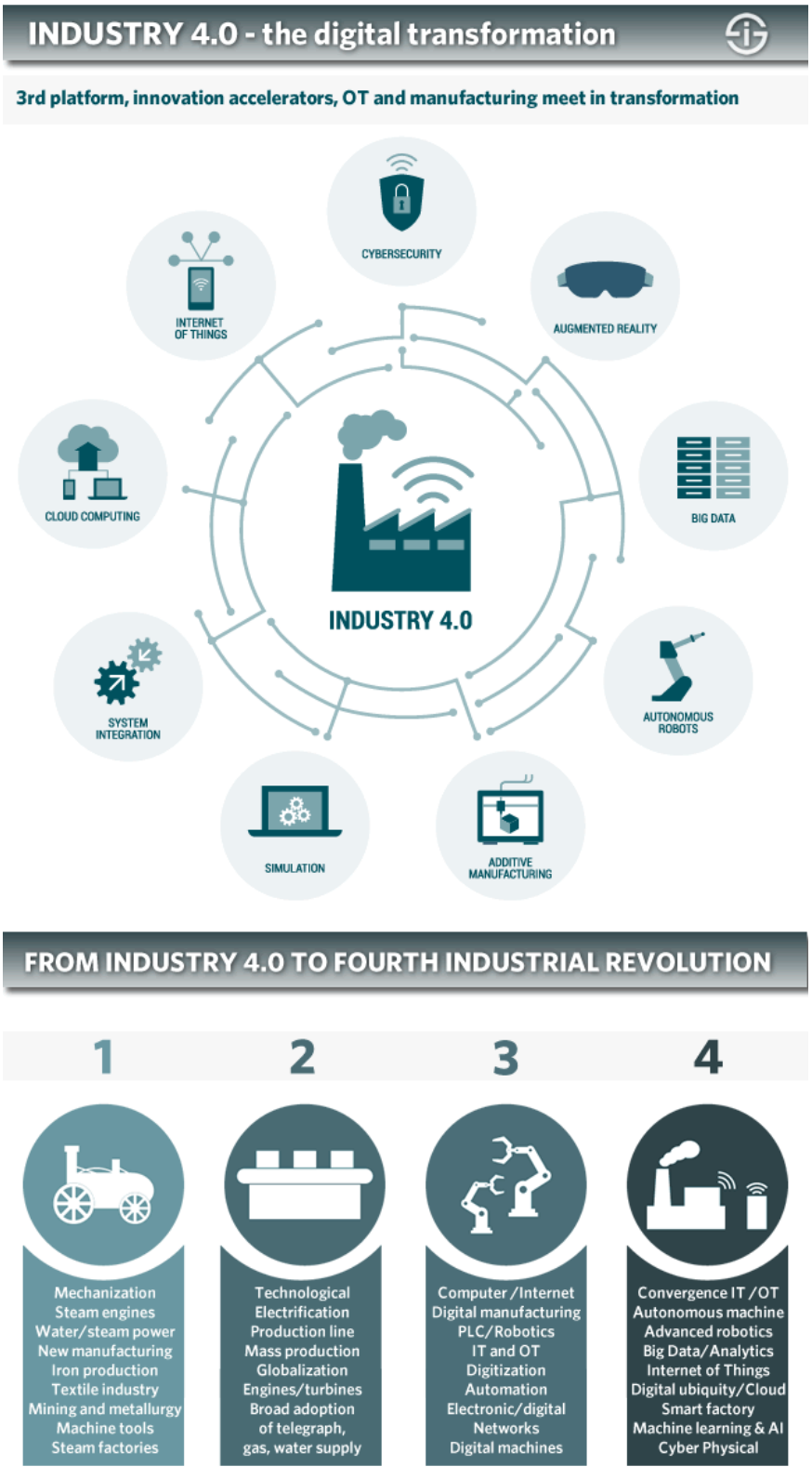


Figure 2. Digital transformation of manufacturing in the fourth industrial revolution[6]

[6] https://www.i-scoop.eu/industry-4-0/

4. Development of a lifelong training pathway for the existing workforce in the manufacturing industry that is responsive to continuous technological advancements which will enable them to maintain a competitive edge throughout their career.
5. Embedding of mobility in the curriculum through placements, exchanges, summer schools, and joint project supervision.
6. Introduction of a joint programme between the partner institutions and beyond, which will allow access to knowledge and deliver skills from diverse fields in Engineering, Computer Science, Data Science and Mathematics, as needed to address the challenges of factories of the future.
7. Embedding of sustainability as an integral part of the curricula with key principles derived from the UN Sustainable Development Goals in order to train the workforce of the future to have a mindset orientated towards environmental and social sustainability.

1.3 About Partner Institutions

Four educational institutions in three countries across Europe are participating in the Smart-Edu4.0 project to develop joint programmes in Mechatronics related subjects which includes undergraduate (UG), postgraduate (PG), CPD and upskilling courses to cover a wide range of participants in partner countries.

Smart-Edu4.0 is being led by Queen's University Belfast in Northern Ireland in partnership with SERC which is a primary delivery arm for government to ensure that the Northern Ireland workforce has the skills to build a successful economy. The *Confirm* institute in the Republic of Ireland is a €45m world-leading Science Foundation Ireland research centre in Smart Manufacturing hosted at the University of Limerick and is best-placed to partner with QUB and SERC from the UK to deliver on the objectives of the project as outlined below. The fourth partner, National Technical University of Athens in Greece has specific expertise in the area of Industrial IoT and wireless communications which are essential elements of any factories of the future platforms. A short account of each institution is provided here for completeness. Further details can be obtained from their respective websites.

Queen's University Belfast, UK (www.qub.ac.uk) - Coordinator

Queen's University Belfast (QUB) is a UK Russell Group research intensive university with a strong track record attracting significant amount of research funding from both EU and non-EU sources. The Centre for Intelligent Autonomous Manufacturing Systems (*iAMS*), where the coordinating project team is based, is a Pioneering Research Programme at QUB comprising an interdisciplinary team of researchers spanning the disciplines of Engineering, Computer Science, Applied Mathematics and Psychology working together to develop innovative technologies and solutions to address the challenges of Industry 4.0. *iAMS* facilities include state-of-the-art cobotic and augmented reality laboratories; the Northern Ireland Technology Centre ATI funded £6 million next generation manufacturing/Industry 4.0 demonstrator platform; the School of Psychology Movement Innovation Lab which combines a virtual reality environment with extensive state-of-the-art motion tracking capabilities for human motion studies; and The Centre for Wireless Innovation which has device-to-device wireless channel measurement capability up to 60 GHz, allowing *iAMS* to work across the full TRL spectrum.

South East Regional College, UK (www.serc.ac.uk)

South East Regional College (SERC) is a large, dynamic regional Further Education (FE) College in Northern Ireland with 1,100 employees and 32,000+ enrolments, helping them to achieve over 20,000 qualifications and over 2,000 work placements every year. Over 80% of SERC's staff hold PG qualifications and have experience from almost 100 different industries. Many of the SERC team

members come from an industry/academic research background and therefore enjoys close working relationship with industry, the community and HE Establishment.

SERC is one of only two Siemens Mechatronics Training Partner, offering specialist mechatronics training within the UK and Ireland. Students at SERC can study for the Siemens Mechatronics Systems Certification Programme, which is an industry focused training programme that has been designed to meet the increasing demand for highly skilled technicians within the manufacturing, engineering sector.

University of Limerick, Republic of Ireland (www.ul.ie)

The Confirm centre for Smart manufacturing, at UL, is ideally placed to lead the Smart-Edu4.0 Joint CPD programmes for manufacturing Industry leadership. Confirm brings an outstanding team of academics drawn from 9 Irish academic organisations, 16 international collaborators, and 60+ industry partners. Confirm academics have supervised approximately 320 postdoctoral researchers. Collectively, they have successfully won €580 million in research funding and have translated their research outputs in terms of 10 spinout companies, 22 licenses, 27 patents filed/granted engaging in real knowledge exchange with companies. Confirm's 60+ industry partners have globally-recognised track records in the full value-chain of the discrete manufacturing sector in Ireland, including product manufacturers (medical devices, electronics, and engineering products), and a diverse range of providers of solutions and services for the manufacturing sector. Both groups are critical to Confirm and Smart-Edu4.0 objectives.

National Technical University of Athens, Greece (https://www.ntua.gr/en/)

NTUA is the oldest and most prestigious educational institution of Greece in the field of technology contributing unceasingly since 1836 to the country's scientific, technical and economic development. The participating group belongs to the NETwork Management & Optimal DEsign Laboratory (NETMODE). Its research interests and areas of expertise focus on management, planning, and design of heterogeneous broadband networks that are based on evolving Future Internet technologies, emphasizing on: autonomic network management, software-defined networks, network virtualization, optimization and resource allocation, Internet-of-Things, Future Internet Research Experimentation, complex and social network analysis, mobile edge computing, data analytics, recommendation systems, multimedia interactive systems and services, topology control, and performance evaluation of stochastic systems.

1.4 Smart-Edu4.0 Deliverables

This multi-institutional, multi-dimensional and multi-disciplinary project has education at its core to help future proof the UK and EU manufacturing sectors. With three HE and one FE institution, the consortium is well-equipped and well-resourced to provide fruitful and far-reaching results from this project. The lead institution, QUB is a member of the Russell Group of top 24 leading research-intensive universities in the UK. Additionally, it's Centre for *iAMS* is leading this initiative to become the UK leader in the area of Smart Manufacturing Education involving diverse disciplines including Electrical, Electronics and Mechanical Engineering, Computer Science, Data Science, Mathematics and Psychology. State-of-the-art factories of the future facilities supported by £7.4 M investment in the last 3 years and an ambitious programme for further development with the establishment of a £90M Advanced Manufacturing Innovation Centre (AMIC) as one of the innovation pillars in the UK government's Belfast Region City Deal investment will ensure the quality of the delivery.

The project aims to deliver the following outcomes:

1. A market research report for Industry 4.0 related vocational, undergraduate, postgraduate and training programmes including CPD programmes.
2. A joint curriculum design suitable for Undergraduate provision in Manufacturing Mechatronics.
3. A joint curriculum design suitable for a Postgraduate degree in Manufacturing Mechatronics.
4. Joint CPD Programmes for Future Leaders.
5. Joint Training Programmes for Upskilling Existing Workforce.
6. A dissemination seminar at the end of the project highlighting the achievements and recommendations made.

2. Background and Motivation

Research carried out by Engineering UK (Excell, 2020) reports an annual need for 124,000 engineers with an annual shortfall of 59,000. Unfortunately, if the skills shortage trend continues to grow as it has for many years without being actively addressed, UK manufacturing will be at risk in the future. With the pace at which new technology emerges, the constant evolution of existing technology and the ever-increasing inter-connectivity of Cyber Physical Systems, it is vital that industrial manufacturing organisations and educational establishments collaborate sooner rather than later to provide relevant updated and new training courses with the former highlighting those areas where training is required and the latter striving to provide suitable resources.

Although the survey results are primarily focussed at Northern Ireland manufacturing industry, engineering skills, in general, are needed across all sectors of the UK and Europe. The data in Figure 3 represents projected annual requirements divided across 10 years (2014-2024) of the employment level and replacement demand of core/related occupations of various manufacturing sectors in Northern Ireland. Highlighted are some of the key occupations related directly to legacy and existing Industry 3.0 level plant/equipment which will become associated with Industry 4.0 level methodologies in the near future as many manufacturing enterprises plan and/or begin to digitally transform their operations in order to stay competitive in their respective markets.

Northern Ireland: projected employment level and replacement demand of core/related engineering occupation for the period 2014 to 2024 - Manufacturing Industries

		Employment level		Change 2014-2024		Replacement demand	
		2014	2024	No.	%	No.	%
Core engineering occupations (4-digit SOC)							
1121	Production managers and directors in manufacturing	3,332	3,373	41	1.2%	1,278	38.3%
1122	Production managers and directors in construction	181	153	-28	-15.3%	69	38.3%
1123	Production managers and directors in mining and energy	40	40	0	0.5%	15	38.3%
2121	Civil engineers	111	106	-4	-3.8%	34	30.9%
2122	Mechanical engineers	793	806	13	1.6%	245	30.9%
2123	Electrical engineers	254	246	-8	-3.1%	79	30.9%
2124	Electronics engineers	199	189	-9	-4.7%	61	30.9%
2126	Design and development engineers	697	689	-8	-1.2%	216	30.9%
2127	Production and process engineers	769	742	-27	-3.6%	238	30.9%
2129	Engineering professionals n.e.c.	889	897	8	0.9%	275	30.9%
2135	IT business analysts; architects and systems designers	176	167	-9	-5.0%	54	30.9%
2136	Programmers and software development professionals	410	360	-50	-12.2%	127	30.9%
2139	Information technology and telecommunications professionals n.e.c.	215	202	-13	-6.2%	67	30.9%
2142	Environment professionals	42	39	-3	-8.1%	13	30.9%
2150	Research and development managers	170	182	12	6.9%	53	30.9%
2461	Quality control and planning engineers	288	287	-2	-0.5%	125	43.4%
2462	Quality assurance and regulatory professionals	312	354	42	13.4%	135	43.4%
3112	Electrical and electronics technicians	137	130	-7	-4.9%	42	30.6%
3113	Engineering technicians	717	642	-75	-10.5%	219	30.6%
3114	Building and civil engineering technicians	44	48	4	8.4%	13	30.6%
3115	Quality assurance technicians	150	119	-32	-21.2%	46	30.6%
3116	Planning; process and production technicians	466	455	-11	-2.5%	143	30.6%
3119	Science; engineering and production technicians n.e.c.	305	263	-42	-13.9%	93	30.6%
3122	Draughtspersons	248	223	-25	-10.1%	76	30.6%
3565	Inspectors of standards and regulations	44	48	4	9.2%	17	38.5%
5211	Smiths and forge workers	51	53	3	5.1%	15	29.8%
5212	Moulders; core makers and die casters	115	103	-12	-10.0%	34	29.8%
5213	Sheet metal workers	525	445	-80	-15.2%	156	29.8%

Figure 3. Employment level and replacement demand of Manufacturing industry in NI (2014-2024)[7]

The projected replacement demand in Figure 3 for most key engineering roles (Electrical, Mechanical, Design & Process) within manufacturing currently stands at almost 31% with those roles related to quality control and planning just below 45%. Although there may be many reasons for these drops in employment levels, the most important question is how can the gap in demand be filled?

Even though there is a need for an injection of new engineers across the UK, the industry still appears to be excited and inundated with talk of the fourth industrial revolution and the need for

[7] https://www.engineeringuk.com/

manufacturing enterprises to begin digital transformation through adoption and integration of industry 4.0, IIoT and smart factory practices.

The buzzwords associated with Industry 4.0 have been whispered in the background since 2011, getting louder every year and seemed to reach a crescendo in 2019 and 2020. It is now almost unthinkable to avoid terms such as IoT, IIoT, Smart Factory, digital transformation or system integration when reviewing any topic associated with the manufacturing or automation industry with equipment vendors, industry experts, company executives, engineers and industrial strategists discussing industry 4.0 and how they are leading the way or beginning their journey into the fourth industrial revolution. There is no denying the fact that the fourth industrial revolution has begun, and this can only exacerbate the shortage of engineering skills in the UK; particularly manufacturing enterprises utilising automation.

These enterprises require engineers with skills, experience and competence in industry 3.0 methodologies and technology (Electrical / Electronic, Mechanical / Manufacturing, Pneumatics / Hydraulics, PLC / HMI). As early preparation for and adoption of industry 4.0 becomes more widespread within the broad scope of manufacturing sectors, enterprises that rely on automation need their current and future engineers to be at least aware of, if not proficient in, industry 4.0 methodologies and technologies (SCADA, System integration, IIoT, industrial networking, Cyber Physical Systems, big data) so they may remain competitive in the rapidly changing manufacturing landscape.

To address the need for manufacturing enterprises to remain competitive in the market, educational establishments need to continue to provide industry with suitable training provision containing industry 3.0 level topics and disciplines; as previously mentioned, to help satisfy the current need for upskilling but perhaps more urgently need to adapt existing provisions to include industry 4.0 level methodologies with a view to raising local enterprise employee’s awareness and understanding of industry 4.0 as a whole. This would enable them to envisage both integration of existing systems and plan to integrate new systems in order to increase efficiencies within their employer’s manufacturing operation.

3. Review of Existing Smart-Edu4.0 Related Programmes

As outlined in Section 1, The Smart-Edu4.0 project is being delivered by four (three HEs and 1 FE) institutions led overall by Queen's University Belfast in Northern Ireland, UK. In this section, the main areas of the programme in each partner country will be reviewed based on market research carried out by individual partners in their respective primary business sector.

3.1 Foundation Programmes

Northern Ireland

SERC as the FE college offers foundation programmes in a range of subjects including Computing, General Engineering, Mechatronic Engineering, Automation and Robotics. They also offer BTEC HNC/HND Engineering qualifications. Worthy of mentioning, and relevant to the Smart-Edu4.0 project, is SERC's Foundation Degree in Mechatronics with Ulster University and their Higher-Level Apprenticeship programme in Mechatronics. A list of all engineering related foundation degrees being offered in Northern Ireland is listed below and can be found on nidirect.gov.uk website.

- Advanced Manufacturing - Foundation degree in electrical and electronic engineering (*Northern Regional College*)
- Advanced Manufacturing - Foundation degree in mechanical and manufacturing engineering (*Northern Regional College*)
- Electrical and electronic engineering - Foundation degree in electrical and electronic engineering (*North West Regional College*)
- Manufacturing engineering (accelerated mode 2.5 years) - Foundation degree in engineering, with specialisms in manufacturing (*South West College*)
- Manufacturing engineering (part-time three years) -Foundation degree in engineering, with specialisms in manufacturing (*South West College*)
- Mechanical engineering - Foundation degree in mechanical engineering (*Northern Regional College*)
- Mechatronic Engineering - Foundation degree in mechatronic engineering (*South East Regional College* and *Southern Regional College*)
- Mechatronic engineering (accelerated mode 2.5 years) - Foundation degree in engineering (with specialisms) - Mechatronics (*South West College*)
- Mechatronic engineering (part-time three years) - Foundation degree in engineering (with specialisms) - Mechatronics (*South West College*)

3.1.1 Upskilling Pathways

Training programs that will be developed as part of Smart-Edu4.0 will provide recognized qualifications to the low skilled and low qualified workforce with a view to provide vocational skills training and award recognized qualifications ranging from introductory broad-based engineering subjects through to specialised Industry 4.0 related modules.

SERC is one of the leading providers in Northern Ireland of Industrial training and CPD courses providing industry specific training for electrical engineering upskilling, CAD training, mechanical/manufacturing upskilling via *Innovation* and *Innovate Us* schemes for SME's within the Engineering Industry in Northern Ireland.

SERC are also the only accredited provider in the Isle of Ireland of the internationally recognised Siemens Mechatronic Systems Certification Programme (SMSCP). The Siemens Level 1 & 2 courses

provide students with a broad-based knowledge of Industry 3.0 fundamentals and align them towards operational competence for Industry 4.0 smart factories of the future.

Successful Level 1 students are recognised as a Siemens Certified Mechatronic Systems Assistant. A Siemens Certified Mechatronic Systems Assistant will function as a well-grounded machine operator in a complex production system, with responsibility for efficient operation of the equipment with minimal down-times.

Figure 4 shows potential Industry 3.0 level vocational training pathways. These pathways will be further developed to include direct routes to Industry 4.0 topics as required. Prospective students could also begin with basic engineering units and incrementally progress through to higher level Industry 4.0 skills units and methodologies. These pathways will target and accommodate learning and training for Low Skilled, Low Qualified and Highly Skilled/Low Qualified workers.

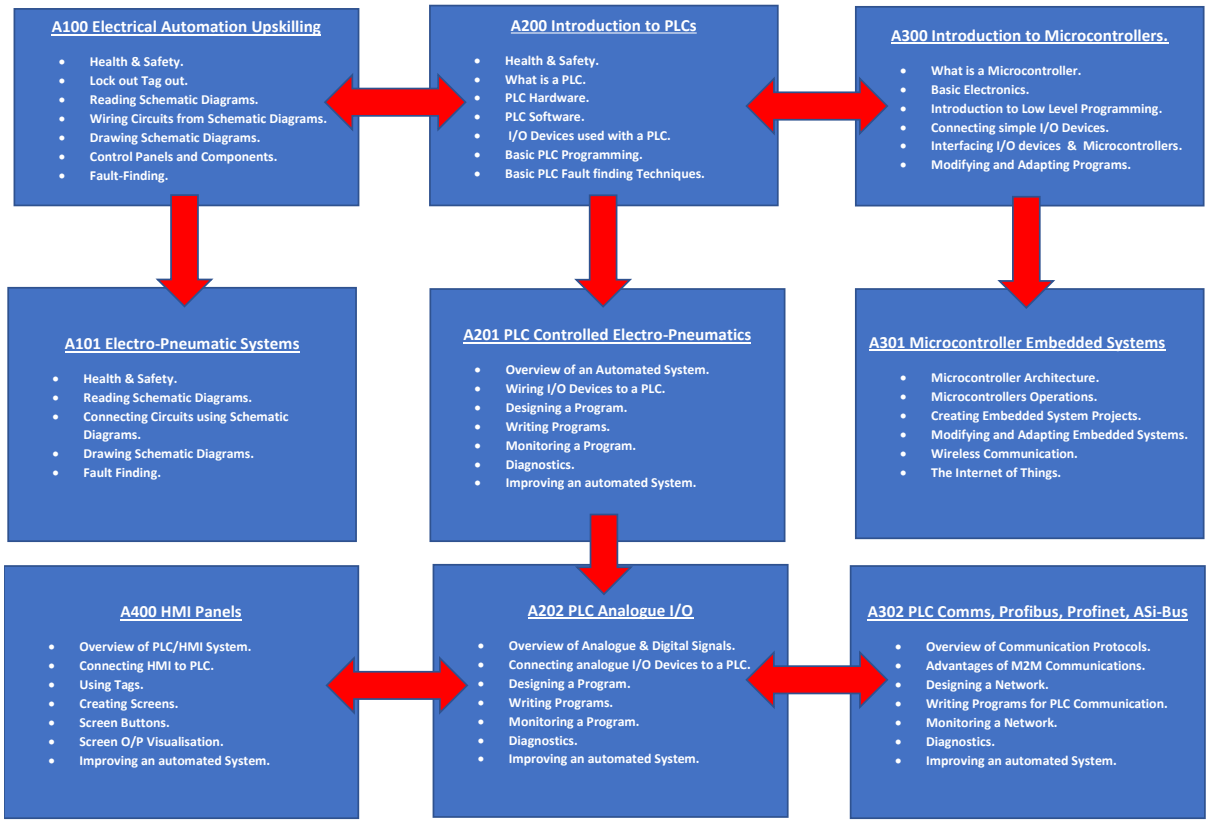


Figure 4. Training Pathways

Further training programmes being offered in Northern Ireland can be found through the NI Direct government website https://www.nidirect.gov.uk/information-and-services/looking-work/training-programmes.

Republic of Ireland

In the Republic of Ireland, although project partner, University of Limerick is not directly involved in offering CPD and upskilling training programmes, some of the relevant courses are being offered under the Skillnet Ireland initiative which is a business support agency of the Government of Ireland

with a specific mandate to advance the competitiveness, productivity and innovation of Irish businesses through enterprise-led workforce development. Skillnet Ireland, through its training delivery networks currently supports over 18,000 businesses nationwide and provides training to over 70,000 trainees. In relation to Industry 4.0, a summary of some relevant training provided by Skillnet is outlined as follows:

Cobotics Skillnet

Cobotics Skillnet is a business network for companies of all sizes in the robotic and automation technology sector. Network companies work collaboratively to share best practice and to respond effectively to the specific skills needs of the sector. The network addresses both technical and non-technical skills needs of members. The objective of this national network is to support the international competitiveness of Irish businesses and employment growth in Ireland by increasing the uptake of robotic and automation technologies.

Cobotics Skillnet is promoted by Irish Centre for Excellence in Robotic Technology (ICERT). Membership of the network is open to private enterprises in the robotic and automation technology sector based in the Republic of Ireland. See Table 6 (Appendix A) for a list of courses currently on offer in Cobotics.

First Polymer Training Skillnet

First Polymer Training Skillnet is a business network for companies of all sizes in the polymer processing sector. The network also supports the use of polymer technologies within the medical device and manufacturing engineering sectors. Similar to Cobotics Skillnet, network companies work collaboratively to share best practice and to respond effectively to the specific skills needs (technical and non-technical) of the sector.

The objective of First Polymer Training Skillnet is to support the growth of Ireland's polymer processors and forms an integral part of the sector. The network continues to forge strong and lasting relationships, working as a partner to industry and strives to empower employers to be competitive in global markets, whilst facilitating the ongoing upskilling and Learning and Development of their employees. First Polymer Training Skillnet is promoted by Polymer Technology Ireland, an Ibec business association. Membership of the network is open to private enterprises in the polymer processing, medical device and manufacturing engineering sectors in the republic of Ireland. See Table 7 (Appendix A) for a list of courses currently on offer.

Irish Medtech Skillnet

Irish Medtech Skillnet is a business network for companies of all sizes in the medical technology and engineering sector. Network companies work collaboratively to share best practice and to respond effectively to both technical and non-technical skills needs of the sector. The objective of this national network is to enhance Ireland's position as an emerging global medical technology hub by developing a strong talent base and enhancing the specialised knowledge and skills that exist within the sector.

Irish Medtech Skillnet is promoted by the Irish Medtech Association, an Ibec business association. Membership of the network is open to private enterprises in the medical technology and engineering sector based in the Republic of Ireland. See Table 8 (Appendix A) for a list of courses currently on offer.

3.2 Higher Education Programmes

Three of the four Smart-Edu4.0 project partners (QUB, UoL and NTUA) are degree awarding HE institutions (HEI) whilst SERC as a FE college also works closely with HEIs to deliver foundation programmes such as the Ulster University Foundation Degree in Mechatronic Engineering and QUB Foundation Degree in Early Childhood Studies. In the following, an overview of programmes in the general area of Mechatronics will be presented which is based on market research carried out in the three partner countries. Note that although Mechatronics is a multidisciplinary subject with courses taken from a range of different disciplines including Electrical and Electronic Engineering, Mechanical Engineering, Computer Science, the market insight was restricted to review programme offerings with specific keywords in their titles. This vary from one partner country to the other, but the aim was to cover a range of such courses within the scope of this project. A country-by-country overview is provided below.

3.2.1 United Kingdom

Competitor analysis was conducted into Undergraduate and Postgraduate Taught courses in the UK with keywords Mechatronics and Robotics in the title. Course title analysis was conducted using UCAS, findamasters.com and a HESA course title database. It is important to note that **the new entrant figures from HESA are always historical and are presented here for 2018/19**. The review will be conducted on an annual basis until the end of the project to have most up-to-date data.

Undergraduate Competitor Analysis

46 UK universities, including 11 Russell Group institutions were found to offer undergraduate programmes with Robotics and/or Mechatronics in the title. HESA data was available for 35 of the programmes, which may suggest that the other courses have been introduced since 2018/19. 23% of new entrants were non-European international and the top sending international countries were China (41), India (31), and Egypt (11). 11% of new entrants were from other-EU countries, and the top sending were Germany (21), Poland (18), and Spain (11). The average number of new entrants per university was 23, of whom, on average, 5 were international students. At Russell Group Universities, the average number of new entrants was 27, of whom on average, 8 were international students.

In Northern Ireland, Ulster University offers BEng / MEng programmes in Mechatronic Engineering; they attracted a total of 49 new entrants in 2018/19, of whom 35 were studying on the full-time BEng Mechatronic Engineering programme.

Further analysis was conducted at course level, assessing the average intake onto programmes with the following titles, (excluding those which were offered in conjunction with another subject e.g. Artificial Intelligence and Robotics).

- Joint programme in Robotics and Mechatronics – 6 UK universities were found to offer a joint programme in Robotics and Mechatronics (data was available for 5). At course level, these programmes attracted an average of 38 new entrants in 2018/19, of whom, on average 11 were international students.
- Mechatronics - 13 UK universities were found to offer a Single honours programme in Mechatronics (data was available for 9). At course level, these programmes attracted an average of 23, new entrants in 2018/19, of whom, on average 6 were international students.
- Robotics - 10 UK universities were found to offer Single honours programmes in Robotics (data was available for 7). At course level, these programmes attracted an average of 19 new entrants in 2018/19, of whom, on average 2 were international students.

Postgraduate Competitor Analysis

35 UK universities, including 12 Russell Group institutions were found to offer PGT programmes with Robotics and Mechatronics in the title. HESA data was available for 29 of the programmes, which may suggest that the other courses have been introduced since 2018/19. The proportion of international students was significantly higher at PGT level; 65% were international and the top sending countries were China (190) and India (77). 11% of new entrants were from other-EU countries, and the top sending countries were France (18), Spain (17), and Greece (10). The average number of new entrants per university was 21, of whom, on average, 13 were international students. At Russell Group Universities, the average number of new entrants was 34, of whom on average, 25 were international students.

Further analysis was conducted at course level, assessing the average intake onto programmes with the following titles, (excluding those which were offered in conjunction with another subject e.g. Intelligent Systems and Robotics).

- Joint MSc programme in Robotics and Mechatronics – 1 UK university was found to offer a joint programme in Robotics and Mechatronics. This course attracted 33 new entrants in 2018/19, of whom, 19 were international students.
- Robotics - 10 UK universities were found to offer straight PGT programmes in Robotics (data was available for 9). At course level, these programmes attracted an average of 22 new entrants in 2018/19, of whom, on average 16 were international students. It is important to note however, that the number of total new entrants ranged from 3-104, and for international new entrants, 1-81. Russell Group universities were generally the top recruiters.
- Mechatronics - 11 UK universities were found to offer a straight PGT programme in Mechatronics (data was available for 8). At course level, these programmes attracted an average of 10 new entrants in 2018/19, of whom, on average 8 were international students.

In conclusion, the Market Insight has revealed that Robotics and Mechatronics are popular subject areas in the UK at both UG and PGT levels attracting significant number of local as well as international students.

Accreditation (UK)

Programmes offered in the UK in the area of Mechatronics and Robotics are typically accredited by one or more of the following professional organisations. An accredited degree enables graduates to apply for Chartered Engineering or CEng status which is highly sought after qualification by the industry.

- Institute of Mechanical Engineers (IMechE)
- Institute of Engineering and Technology (IET)
- Institute of Measurement and Control (InstMC)

3.2.2 Republic of Ireland

In the Republic of Ireland, the education and training system has begun to respond to the challenges of Industry 4.0 and existing programmes are being leveraged to deliver the skills required at all levels to respond to Industry needs, including those of the Manufacturing sector.

At management level there are a number of programmes available such as Enterprise Ireland's Management Development Programme, Innovation for Growth, and the Tailored Management

Company Support - all of which are accessible to both indigenous and foreign-owned firms; the LEOs Management Training Programme and a number of management development programmes provided by Skillnet Ireland and via the Springboard+ programme. These programmes will provide industry in the manufacturing sector with the opportunity to develop the strategic leadership and management skills required to deliver on Industry 4.0 implementation strategies. Furthermore, programmes developed by the Department of Education and Skills (DES) and it's agencies have been leveraged to meet the new skills needs arising from Industry 4.0 such as Springboard+ and the Original Equipment Manufacturing Apprenticeship and Manufacturing Apprenticeship Programmes. Also, the new ICT Skills Action Plan aims for a pipeline of ICT professionals that will underpin the ICT skills for Industry 4.0.

To support individual firms to develop and implement training plans that meet their specific needs, the 'Regional Skills Fora', established by DES, acts as a single contact point with employers in each region allowing them to connect with the range of services and supports available across the education and training system. Work is already ongoing through the 'Regional Skills Fora' and the 'Skills for Growth Initiative' to give employers the necessary tools to identify their skills needs, including those related to Industry 4.0. Once skills needs are identified, the Regional Skills Fora will facilitate engagement between enterprise and the Education and Training System to respond to these needs.

Undergraduate Competitor Analysis

In the Republic of Ireland, a range of subjects related to Mechatronics were reviewed. Similar to the UK market, programmes with specific keywords (Mechatronics and Robotics) were investigated, however only a few degrees were found. Hence the list of keywords was expanded to include Mechatronics, Automation, Robotics and Manufacturing for this report. Altogether 16 undergraduate programmes were found with the above keywords in their titles which are listed in Table 1.

Postgraduate Competitor Analysis

At PG level, the SUFI Industry Fellowship programme, for example, will support employees to spend time in academic environments participating in collaborative RUDI, receiving training and developing new skills in Industry 4.0. In addition, the Irish Research Council Enterprise Partnership Scheme will support the placement of PG or postdoctoral researchers into firms to work on Industry 4.0 activities: the upskilling element occurring through the knowledge transfer from the Industry 4.0 experts to firm employees.

Moreover, the Advanced Manufacturing SFI centres (Confirm and I-Form), have targets set for the number of PhD graduates to be directly supported by the centres, and these centres are also developing masters' programmes in Industry 4.0 related areas and recruiting a high number of postdoctoral researchers. These graduates and postdoctoral researchers will be highly skilled in technical areas under the Industry 4.0 umbrella and will be key to producing a pipeline of specialist skills in Industry 4.0 for enterprise.

As listed in Table 2, five universities were found to offer PG qualification (taught programmes only) in Mechatronics and Manufacturing Engineering which includes project partner, University of Limerick.

Table 1. List of undergraduate programmes in Ireland

Institution	Course Title	Duration
Athlone Institute of Technology	BEng Automation and Robotics	3 years
Dublin City University	BEng Mechatronic Engineering	4 years
Dublin City University	BEng Mechanical & manufacturing Engineering	4 years
Limerick Institute of Technology	BEng in Industrial Automation and Robotic Systems	3 years
Limerick Institute of Technology	BEng (Hons) in Industrial Automation and Robotic Systems	4 years
Munster Technological University - Cork	BEng (Hons) Advanced Manufacturing Technology	4 years
Munster Technological University - Cork	BEng (Hons) Advanced Manufacturing Technology	4 years
Munster Technological University - Tralee	Bachelor Degree Mechanical & Manufacturing Engineering	3 years
Munster Technological University - Tralee	BSc (Hons) in Manufacturing Engineering	4 years
Munster Technological University - Cork	BEng (Hons) Advanced Manufacturing Technology	2 years
National University of Ireland Maynooth	BSc Robotics and Intelligent Devices	4 years
Technological University Dublin	BEng (Hons) in Mechatronic Engineering	4 years
Technological University Dublin	BEng (Hons) in Automation Engineering	4 years
Trinity College Dublin	BA and BA (Hon) Mechanical & manufacturing engineering	4 years
Waterford IT	BEng (Hons) Automation Engineering	4 years
Waterford IT	BEng (Hons) Mechanical & Manufacturing Engineering	4 years

Table 2. List of postgraduate programmes in Ireland

Institution	Course Title	Duration
Dublin City University	MEng Mechatronic Engineering	5 years
University of Limerick	MEng Mechatronics	1 year
Dublin City University	MEng Mechanical & manufacturing Engineering	5 years
University College Cork	MEngSc Engineering - Mechanical Engineering (Manufacturing, Process and Automation Systems)	1 year
Trinity College Dublin	M.A.I. Mechanical & manufacturing engineering	5 years

Accreditation (RoI)

Degree programmes in the Republic of Ireland are professionally accredited by the following bodies.

Engineers Ireland

QQI – Quality and Qualifications Ireland

3.2.3 Greece

In this section, an analysis of the set of UG and PG programmes and courses is presented that are delivered by Greek academic institutions and are targeted to Industry 4.0 solutions. The analysis mainly includes programmes that support courses related to manufacturing mechatronics, Industry 4.0, industrial IoT and sustainability aspects within Industry 4.0. The objective is to depict the current situation in Greece regarding the existence of programmes related to the material within the scope of the Smart-Edu4.0 project.

Undergraduate Competitor Analysis

As before, a set of keywords relevant to Smart-Edu4.0 project were used to identify relevant undergraduate programmes in Greece. It was found that Greece mostly offers traditional undergraduate pathways with further specialisation at PG level. As such, no specialised UG pathway in Mechatronics could be found. However, there are a number of technical courses on offer in various Greek institutions which are highly relevant to this project. Such courses, mostly taught in Greek, are generally delivered through engineering studies programmes, in departments related to mechanical engineering, mining and metallurgical engineering, industrial design and production engineering, electrical engineering and computer science. Upon a detailed study of the curriculums provided by a large set of Greek universities, a set of undergraduate courses were determined that tackle the industry 4.0 challenges and have been divided into six categories as depicted in Figure 5. The categorization of the courses is indicative since some of them have overlapping areas.

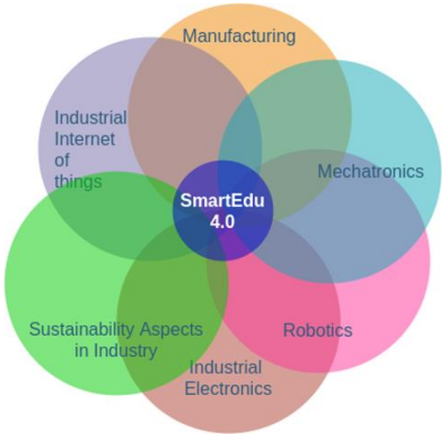


Figure 5. Classification of Greece-based courses in six categories

Mechatronics

Courses of this category introduce the students to collaborative systems consisting mainly of mechanical and electrical parts with the aim of designing innovative products and processes. Issues related to the introduction of computer science and automatic electronic control as integrated components of a computer system are studied. The three basic concepts analyzed are engineering, control (feedback processes) and computers (implementation of controls in hardware and software) and their collaborative application which can lead to improved and low cost systems.

Manufacturing

Manufacturing courses include Computer Aided Engineering, Systems Modelling and Simulation, Advanced Measurement Systems and Data Analysis, Automation and Robotics, Quality Management

& Reliability, Global Manufacturing Enterprise Business Development, Logistics and Global Supply Chain Management and different research Methods for Engineering Projects.

Industrial Electronics

Courses of this category focus on presentation of power semiconductors and electronic power converters such as uncontrolled and controlled rectifiers (AC / DC), DC-DC converters, AC converters (AC / AC) and power inverters (DC / AC). Also include the principles of control of AC and DC electric motors and electric drive systems as well as electronic controllers for industrial motors, elements of industrial electrical installations and automation. PID control in industrial applications, introduction to PLCs and application of microprocessors and digital signal processors (DSP) in the industrial environment are concepts that are specified in the learning units of the courses. Laboratory experiments vary from course to course (e.g. analysis of simple electronic setups that include rectifier circuits (AC / DC) using diodes and thyristors and control of electric motors with power electronic inverters (DC / AC))

Industrial Internet of Things

Courses of this category aim to engage the students in the vast array of technologies that can be used to build an industrial internet of things deployment. Students encounter market sizes and opportunities, operating systems, networking concepts, many security topics, how to plan, staff and execute a project plan, sensors, file systems and how storage devices work, machine learning and big data analytics, techniques for debugging deeply embedded systems and finally promoting technical ideas within a company.

Robotics

Courses related to Robotics vary considerably in terms of depth they reach. They frequently include dexterous robot manipulation, kinematic control of redundant manipulators, manipulability and dexterity measures. They also tackle interaction control of robot manipulators, force control, impedance control, hybrid control and visual servoing of robot manipulators. Dexterous multifingered robot hands, kinetostatic analysis and control of robot grasping are mentioned in some curriculums while other include intelligent autonomous mobile robotics: elements of mechatronic design (locomotion, sensors), kinematic modelling, control architectures, environment mapping and representation, perception and localization, sensor fusion, path planning and robot learning. Moreover, applications of integrated robotic systems, mobile robotic manipulators, collaborative robotics, shared human-robot control and telerobotics are found to be presented in a wide set of courses related with robotics.

Sustainability aspects in Industry

Sustainability aspects in Industry courses prepare students to be able to understand and assess sustainable manufacturing concepts and apply this to industry cases. The delivered knowledge focuses on advanced research about the academic theory of sustainable and circular manufacturing, knowledge about manufacturing systems design, necessary processes for Industry 4.0 manufacturing and knowledge about modelling methods for analysis and selection of solutions.

See Table 9 in Appendix B for a detailed list of the main courses provided per category and the offering institutions.

Postgraduate Competitor Analysis

In contrast to UG studies, a small set of PG programmes are being offered related to Industry 4.0 subjects.

A programme dedicated to Mechatronics (Graduate Program in Mechatronics) is offered by the **University of Western Macedonia**. The programme leads to a Masters Degree in Mechatronics offered by the Department of Electrical Engineering of the Technological Education. This program is a 3-semester Masters program and is addressed to graduates who wishes to gain experience in the design and implementation of efficient, economical and reliable systems and products by merging the principles of mechanics, electronics, and computing. It covers various subjects in the areas of electronics, microprocessor-based design, data acquisition, power systems, mechanical systems design, mechanical behaviour, and materials. Courses can be taught in Greek and in English. Among others, it includes courses related to Microcontrollers and Logic Programming, Industrial Robotics and Mechatronics Project Design.

A set of programmes are offered in the area of industrial automation systems. These include the postgraduate programme on Automation Systems offered by the School of Mechanical Engineering of the **National Technical University of Athens**, the MSc in Industrial Automation offered by the **University of West Attica** and the MSc in Advanced Industrial & Manufacturing Systems offered by the same institution. In the area of robotics, a MSc in Robotics is provided by the **International Hellenic University**.

Similarly, various programmes focus in the area of Industrial Internet of Things (IIoT). These include the MSc in the Internet of Things and Intelligent Environments provided by the University of West Attica, the Postgraduate Program entitled "Digital Culture, Smart Cities, IoT and Advanced Digital Technologies" offered by the Department of Informatics of the University of Piraeus and the MSc programme in the Internet of Things: Intelligent Environments in Next-Generation Networks provided by the University of the Aegean. The objective of the latter is to provide systematic and specialized training in the design and development of intelligent environments in next-generation networks, using the Internet of things as a baseline.

A list with the aforementioned postgraduate programmes along with details for the type of studies offered per programme is provided at Table 10 (Appendix B).

Based on the provided data regarding the available courses at UG and PG level in Greece, it can be said that a plethora of courses related to Industry 4.0 aspects exist, in accordance with the evolving trend in the development of courses related to mechatronics and robotics. Most of the developed curriculums are taught in Greek delivered on campus (not considering the current situation due to Covid-19 where all the courses are realised online). However, given that each curriculum focuses on a specific technology applied in Industry 4.0, it seems that a holistic programme that can provide valuable information for aspects of mechatronics, automation, robotics and sustainability is missing thus identifying a clear gap in that area in Greece.

Accreditation (Greece)

Programmes in Greece are accredited by the following professional body.

- Technical Chamber of Greece (TEE-TCG)

3.2.4 Analysis of Modules

A total of 58 programmes from a number of institutions from Ireland, Greece and UK have been investigated and their modules analysed. The majority of programmes searched were UG BEng/MEng as well as PG MSc with keywords used as explained before, with the exception of Greek institutions, where Mechatronics/Robotics or similar subjects are not offered for UG studies. In summary, the size of data drawn from each partner country is mentioned in Table 3.

Table 3. UG and PG Programme numbers in partner countries

Countries	BEng	MEng	MSc
Ireland	14	2	1
Greece	-	3	6
UK	15	14	7

It is worth mentioning that the analysis is by no means exhaustive but designed to capture trends in modules (courses) and subjects taught. Although the intention was to identify programmes directly related to Mechatronics, degrees offered in the areas of Manufacturing, Robotics and heavily related programmes in Mechanical/ Electrical Engineering were also included.

Modules Groupings

To capture relatively accurately the type of subjects taught, the modules were categorised in 13 groups as tabulated in Table 4.

Table 4. Groupings based on common modules found across the three countries

Group No.	Group Name	Group No.	Group Name	Group No.	Group Name
1.	AI/Machine Learning	**2.**	Power/Energy	**3.**	Programming
4.	Computer Architecture/ Databases	**5.**	Communications	**6.**	Robotics
7.	Embedded Systems	**8.**	Cloud/Edge/IoT	**9.**	Non-Engineering Skills
10.	Controls	**11.**	Mathematics	**12.**	Mechatronics
13.	Manufacturing				

Representative modules for those groups are listed below noting that UG are PG modules are not differentiated here.

Group 1 – AI/Machine Learning: Machine Learning and Neural Networks, Deep Learning, Behavioural Computing, Reinforcement Learning, Neural Networks, Intelligent systems methods, Bio inspired Computing, Computational Intelligence, Modelling Persistent Data, Data Mining and Machine Learning, Evolutionary Computing and Genetic Programming.

Group 2 – Power/Energy: Power technology, Electrical power systems and machines, Energy systems, Sustainable energy, Sustainable systems and energy, Power electronics, Energy auditing and energy management, Sustainable energy systems, Electrical machines, Power Grid Systems, Energy Management, Industrial Power Systems, Power Electronics and Drives, Power Control.

Group 3 – Programming: Object oriented programming, CAD, CAM, Computing for Engineers, C programming, Software Engineering, Web programming, Web Development, Procedural Programming.

Group 4 – Computer Architecture/Data: Data Communications, Data Acquisition, Algorithms & Data Structures, Operating Systems, Computer Architecture.

Group 5 – Communications: Measurement and Signal Processing, Digital Signal Processing, Communication Systems, HMI & SCADA, Industrial Communications, Industrial Information Systems, Signals, Systems and Communications, Antennas and RF Systems, Wireless Communications

Group 6 – Robotics: Mobile Robotics, Motion Control and Robotics, Robotics and Vision Inspection, Automation and Robotics, Industrial Robotics, Robotic Control Systems, Mobile and Humanoid Robots, Human Robot Interaction, Assistive Robotics, Soft Robotics, Aerial Robotics, Biomechatronics and Medical Robots, Space Robotics, Cognitive Robotics, Swarm Robotics.

Group 7 – Embedded Systems: Embedded Systems, Digital and Analogue Electronics, "FPGA, DSPs, GPUs", Cyber-physical Systems, MicroControllers, ASICs and Digital Design, Digital and Embedded Systems, Embedded Software, Real Time Systems, Microprocessors, Real Time Embedded Programming, Real Time DSP.

Group 8 – Cloud/Edge/IoT: Sensors, IP Networking, SCADA & Industrial Networking, Cisco Networking, Sensors and Signal Processing, Sensors.

Group 9 – Non-Engineering Skills: Engineering Economics, Entrepreneurship for engineers, Project planning and research, Innovation Management, Regulatory Affairs, Creative Design, Philosophy and History of Science, Micro and Macro Economics, Marketing, Engineering Risk Management, Business Awareness, Safety and Sustainability.

Group 10 – Controls: Automation, Control, Manufacturing Automation, Control Systems and Automation Engineering, Instrumentation & Automation, Control Engineering, PLC, Statistical Process Control, Control Engineering and Robotics, System Dynamics, Computer Control Systems, Nonlinear Control, Multivariable Control Systems, Intelligent Control and Robotics, Adaptive and Robust Control, Logistics, System Identification, Intelligent Systems Control, "Fault Detection, Isolation and Recovery".

Group 11 – Mathematics: Dynamics, Mathematics, Mathematic for Engineers, Numerical problem solving for Engineers, Probability and Statistics, Linear Algebra and Calculus, Differential Equations and Numerical Methods, Stochastic Optimization, Metaheuristic optimization, Operations Research, Linear Programming, Game Theory, Combinatorial Optimization, Nonlinear Programming, Dynamic Programming, Logic, Graphs and Algorithms.

Group 12 – Mechatronics: Mechatronics Practice, Mechanical Systems Design, Electromechanical system design, Mechatronics Systems Simulation and Control, Mechanics for Mechatronics and Robotics, Biomechatronics.

Group 13 – Manufacturing: Materials and Processing, Manufacturing Systems and Organisation management, Polymer engineering, Heat transfer, Mechanical workshop, Quality, Design for manufacturing and assembly, Whole Life Cycle Analysis, Manufacturing systems simulation, Six Sigma Green Belt Quality, Mechanical Design and Manufacturing, Manufacturing Quality Systems, Supply Chain Management, Facility Simulation and Reliability, Optimal Industrial Systems Design, Enterprise Resource Planning Systems, Factory Simulation.

Two additional groups could be further added that correspond to mechanical and electrical engineering related modules. Such modules are present in the vast majority of mechatronics related programmes but are not listed in above for a more focussed study.

A visualisation of the results analysed can be seen in Figure 6 below depicting the percentage of appearance of specific modules in the three partner countries.

It is clear that certain groups of modules are commonly taught in all three countries (see groups with similar frequencies). For example, the majority of programmes involve modules related to Controls and Mathematics whereas Programming and Power/Energy related modules are also substantially offered. Subjects related to Mechatronics and in general Manufacturing are taught consistently in more than half of the programmes analysed. It is worth noting that fundamental subjects from Electrical and Mechanical Engineering disciplines, although not depicted here, are also present in virtually all BEng/MEng programmes. In addition, one can observe a few elements differentiating one country from another; for example, UK-based courses are more focussed on Programming-related subjects compared to partner countries. On the other hand, Irish institutions focus more on Mathematics and Manufacturing, whereas topics related to Embedded systems, Robotics and AI are taught less frequently but are still available sporadically nonetheless. In Greece, there is a trend for MSc programmes to include modules related to IoT/Edge Computing/sensor networks which is minimal in the Irish market and non-existent in the UK. Another interesting grouping is related to Non-Engineering skills or soft skills modules which are being offered in all countries and found in nearly half of the programmes analysed.

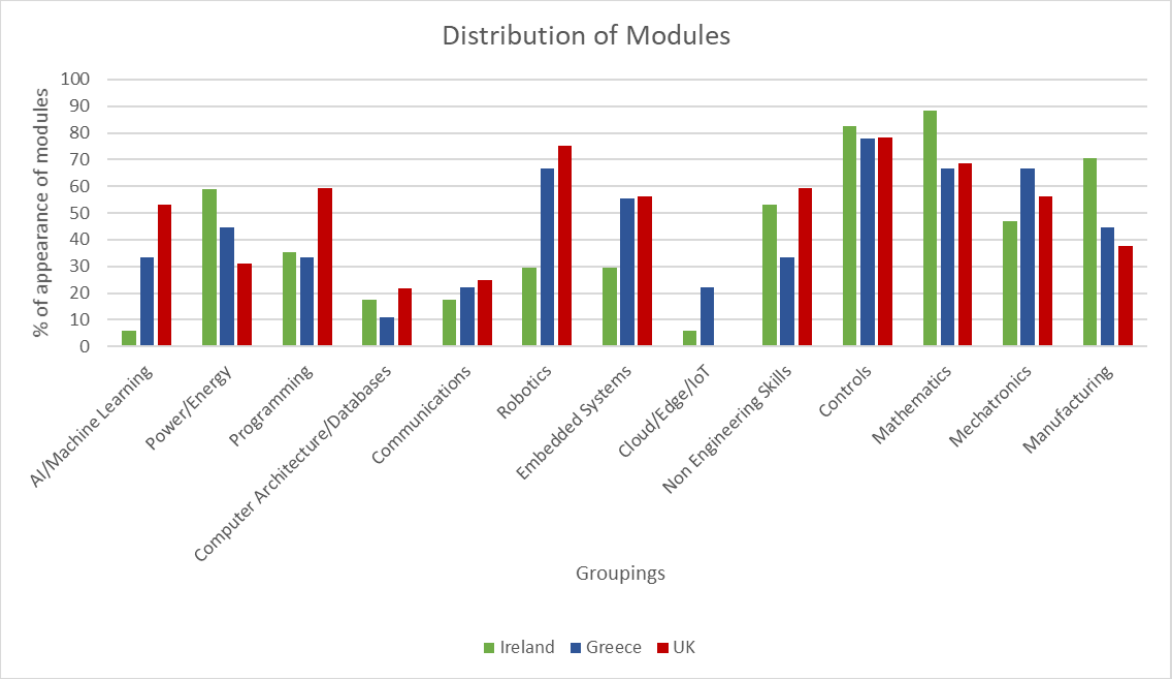


Figure 6. Frequency of Groups 1 - 13 in Ireland, Greece and UK

4. Industry 4.0 Market Research Survey March 2020

Project partner, SERC conducted an online survey in March 2020 of a number of local companies operating in Northern Ireland asking them various questions regarding the company's operation. The survey was an initial means of contact with the local industry in an attempt to ascertain the general awareness and current adoption of Industry 4.0 & IoT technology and methodology, if any.

Ten companies with a broad range of engineering enterprises were selected for the scoping survey. These are listed in Table 5 below:

Table 5. Survey of companies located in NI

Company Name	Company Primary Operation	Survey Completed
Moy Park	One of the UK's top 15 food companies, Moy Park is Northern Ireland's largest private sector business and one of Europe's leading poultry producers.	**Yes**
Whale	A well-known innovative global supplier of freshwater, bilge, waste pumps and heating systems for the marine, caravan and industrial market. Whale design, manufacture and assemble their own products in house.	**Yes**
EAE	EAE (Electronic Automation Engineers) are a specialised enterprise providing bespoke or predefined automation system design and integration of machinery and manufacturing systems. EAE have operations in Bombardier, Spirit, Airbus and Lockheed Martin.	**Yes**
Thales	Thales is a global enterprise providing engineering solution many sectors, aerospace, space exploration, ground transportation, digital identity & security and defence & security. Thales Belfast operations design, manufacture and assemble military weapon control systems for integration into tactical platforms.	**Yes**
Linamar	Montupet now operate under Linamar, a global manufacturing company. In its Belfast plant the company is an aluminium foundry producing castings for use in the automotive industry.	**Yes**
Johnsons Coffee	Johnson Brothers are a long-established coffee roasting and brewer who manufacture, supply, and maintain coffee machines across NI.	**Yes**
Denroy Plastics	Denroy Plastics are a world leading innovator in the design, manufacture, assembly and supply of engineered polymer components, products, and solutions globally to the aerospace, automotive, commercial and defence sectors.	**No** to date
Rich Sauces	Rich Sauces manufacture and supply products to over 4000 businesses in 10 countries. They are Ireland's leading mayonnaise manufacturer supplying a range of dressings, sauces and bouillons to the food service industry.	**No** to date
BE Aerospace	BE Aerospace are a manufacturer of aircraft passenger cabin interior products for the commercial and business jet aircraft markets.	**No** to date
Pritchitts	Operating under Lakeland Dairies Pritchitts are a global market leader in the manufacture of dairy based products.	**No** to date

The list of 10 most relevant questions (Questions 4 – 13) from the survey is provided below and their results are shown pictorially from Figure 7 - Figure 12.

4. Which processes does the company employ?
5. Provide a short description of what the company does.
6. Which production/processing equipment does the company use?
7. A short description of the main production/processing equipment the company uses.
8. Which technology does the company use?
9. Provide a short description of the main production/processing data gathering systems used.
10. Are the company aware of Industry 4.0?
11. Are the company aware of IoT?
12. Which aspects of Industry 4.0 & IoT are the company interested in?
13. Provide a short description of the aspects of Industry 4.0 & IoT the company may adopt in the future.

Analysis of company responses

Six of the ten companies responded to the survey providing suitable data to develop a general impression of the level of awareness within the local enterprise regarding Industry 4.0 & IoT.

Figure 7 shows that 4 out of 6 companies produce individual parts and track those products through the manufacturing process with half of them assembling the finished product on site. In Figure 8, it can be seen that all but one of the companies are using automated, CNC and PLC controlled production techniques with 4 utilising multi-axis robot arm part handling with conveyor belt transference whilst employing machine to machine system integration, indicating a high degree of Industry 3.0 methodology. It is interesting to note that the majority of those companies (67%) perform manual production techniques, however, it should also be mentioned that manual assembly in most cases cannot be completely avoided due to the intricate human dexterity and manipulation required to assemble final finished products.

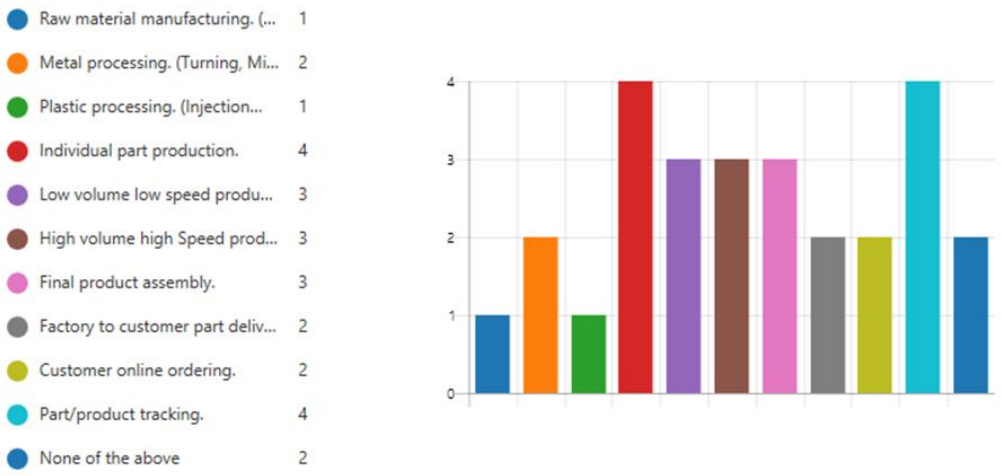


Figure 7. Responses to Question 4

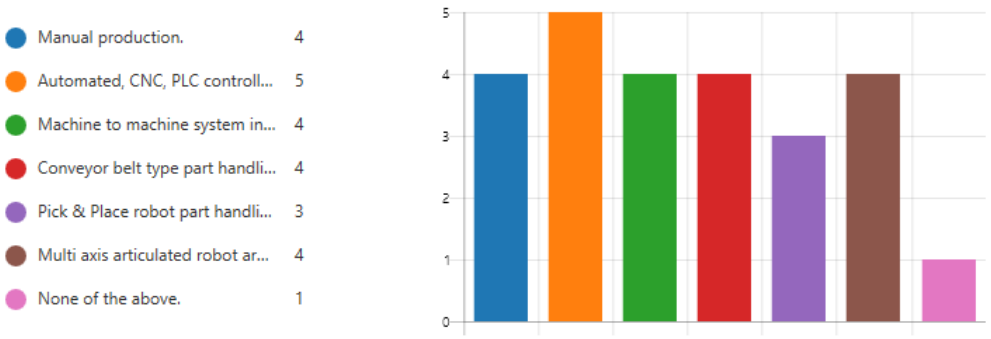


Figure 8. Responses to Question 6

Correlating the data from Questions 7 (Figure 9), 8 (Figure 10) and 9 (Figure 11) reveals that all the companies surveyed utilise production processing equipment that relies on PLC automated control with localised sensor data acquisition, 67% are using SCADA systems (Supervisory Control & Data Acquisition), Cloud Computing and Data Storage with half of the companies also using ERP (Enterprise Resource Planning) systems. This illustrates that most of the companies surveyed have various systems in place to gather data in order to make their production operation more efficient while

reducing wasted product. These are typical examples of enterprises operating at an Industry 3.0 level evidently engaged in data acquisition procedures although seemingly at a localised production cell level. One-third of the companies are using standard data base software with two-thirds using dedicated ERP (Enterprise Resource Planning) and MES (Manufacturing Execution Systems) systems. One of the six companies surveyed still manually collects information whilst another one utilising an Industry 4.0 "Smart Factory" solution ready package: iFactory.

ID ↑	Name	Responses
1	anonymous	Gravity and Low Pressure Casting machines, core shooting machines, melting furnaces, CNC machining centres
2	anonymous	Injection moulding shop Manual assembly of products Lab testing 3D printing
3	anonymous	coffee blender, roaster, packaging machinery
4	anonymous	Weighing, mixing, tumbling, conveyors, lifting, cooking, frying, freezing, packing, check weighing, metal detection,checkerighing, metal detection, shrink wrapping, boxing machines.
5	anonymous	An extremely modern machine shop with a full range of automatic multi-axis machinery. We also have several industry standard clean-room facilities with limited automation.
6	anonymous	PLC & Robotics

Figure 9. Responses to Question 7

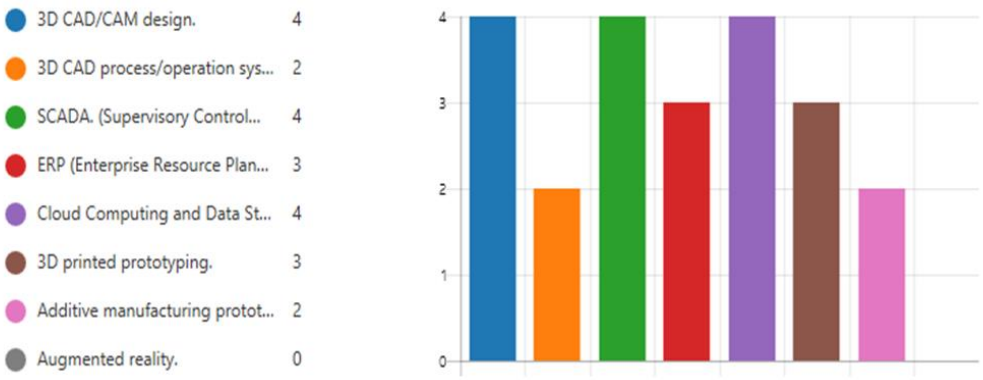


Figure 10. Responses to Question 8

ID ↑	Name	Responses
1	anonymous	All of the above
2	anonymous	MS access databases, SQL databases, ususal MS Office based
3	anonymous	manual system
4	anonymous	Incal system for Temperature and pressure monitoring, Inova system for weighing system for products and waste management. TMS for personnel clockings MP2 and SAP systems for work orders for machine maintenance and also for ordering parts.
5	anonymous	Not much experience in this, however, within the military defence industry generally, due to security, software is written in-house, or of-the-shelve software is adapted and honed to suit.
6	anonymous	IFactory

Figure 11. Responses to Question 9

In response to Question 10, interestingly despite 67% of the enterprises operating at mid-level Industry 3.0, only two out of the six companies are aware of Industry 4.0, two are unaware of it and two remain unsure of what that means.

Correspondingly, the same degree of awareness is evident in response to Question 11 concerning IoT with half being aware of it, two unaware and one being unsure. It is probable that those individual respondents having heard of The Internet of Things may only be relating the technology to the domestic and commercial markets, not realising that Industry 4.0, IoT and indeed IIoT all operate together, aimed at the same objectives; data harvesting to increase productivity and efficiency while reducing waste at the field level in the manufacturing environment whilst also acquiring customer/product related data and feeding it back into the system for trend analysis to further improve efficiency.

In response to Question 12 (Figure 12) most companies were found to be interested in Automated System Integration with half having expressed interest in Robotics/Cobotics, IoT and Smart Sensors. This establishes the fact that at least 50% of the enterprises surveyed wish to expand or enhance their automated Industry 3.0 processes, perhaps towards an Industry 4.0 methodology. Some of the responses include:

"Anything that can be automated to reduce manual workload."

"*It is part of our corporate strategy to adapt aspects of Industry 4.0, and much of our factory processes are already in place. For some of our older machines there is a plan to migrate more data collection and for all NEW production lines we will be adapting to be in line with our corporate strategy*."

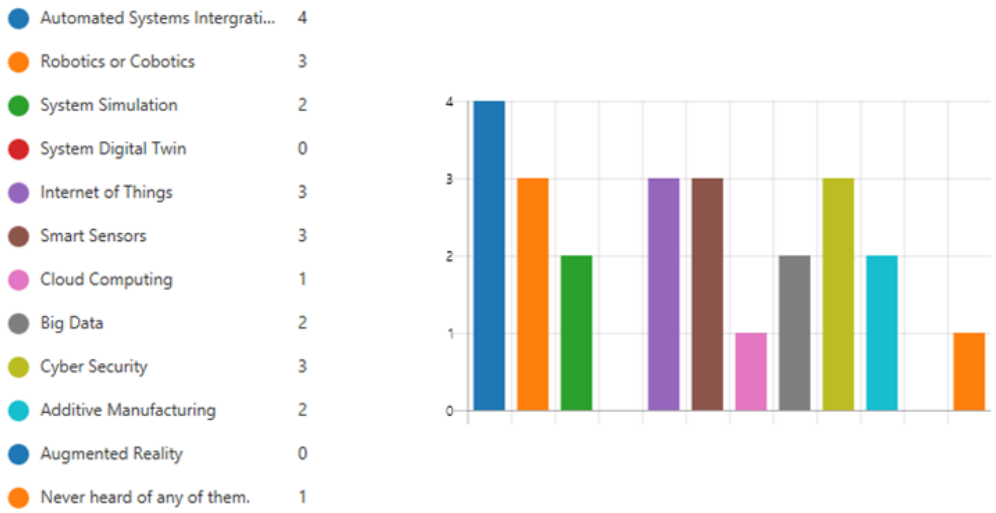


Figure 12. Response to Question 12

One must realise that the survey responses are the opinions of individuals who may not necessarily be operating or involved directly at the field level of their respective production facility, highlighting that like almost all industry revolutions and technology evolutions that have come before, awareness and in most cases culture change are a crucial element in the adoption of new operational processes.

5. Identifying Gaps

Having reviewed the current programmes offered in the three partner countries, it can be generally concluded that Mechatronics and related Industry 4.0 topics are becoming increasingly popular subject areas at not just UG and PGT levels but also forming a vital part of technical and vocational sectors. From the market research in the three partner countries, it appears that UK is generally leading in this category with 46 UG and 35 PG programmes followed by the Republic of Ireland with 11 UG programmes whilst 5 in PG. Based on the collected data, there are no UG programmes in Mechatronics being offered in Greece, however, some PG programmes in that area are available.

In the UK, only 11 out of 24 Russell Group (RG) universities offer UG programmes in Mechatronics/Robotics related areas whilst in PG, 50% of them offer relevant PG degrees. In terms of student numbers, it can be seen from Figure 13 below that PG attracts significantly higher number of international students compared to local (Figure 13 (a) and (c)) whilst it is the opposite for UG programmes (Figure 13 (b) and (d)). Having said that, the overall number of students in UG still outweighs the student population in PG. Additionally, the average number of new UG entrants per university was 23, of whom, on average, 5 were international students. On the other hand, the average number of new PG entrants per university was 21, of whom, on average, 13 were international students. No such data is available for other partner countries at the time of this survey.

In the Republic of Ireland, 8 institutions were found to offer UG whilst 4 universities offer PG programmes in areas related to Mechatronics, Automation, Robotics and Manufacturing. Using the same two keywords (Mechatronics and Robotics) used in the UK, the list drops to just 5 in UG and 2 in PG.

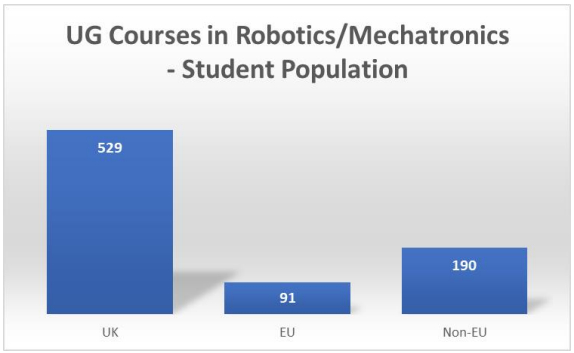
In Greece, none of the institutions were found to offer an UG programme in Mechatronics or Robotics whilst only a handful of universities offer degrees in the relevant disciplines. It should be noted that most universities offer conventional pathways with an element of specialisation in the final 2-3 years. This means that a number of relevant modules are indeed being taught at both UG and PG level in Greece, however a holistic programme that can provide valuable information for aspects of mechatronics, automation, robotics and sustainability is missing thus identifying a clear gap in that area.

It was also established that offering a joint Robotics and Mechatronics programme at UG level is advantageous for attracting students. Whilst there were technically less universities offering a joint option (vs single honours Robotics or Mechatronics), the average intake of the joint course was considerably higher.

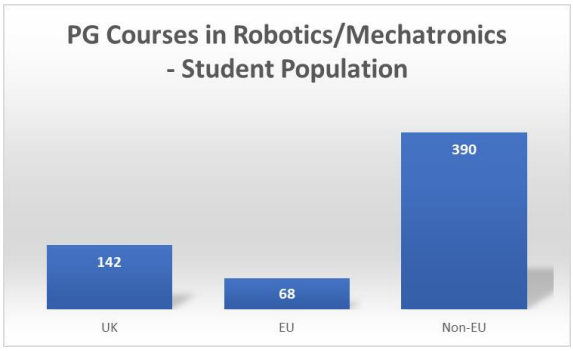
Development of new training programmes

In addition to the expansion of existing curriculum there exists an opportunity for the consortium to lead the way with the development of new, specialised training programmes for those already working in the manufacturing sector and who are seeking to expand their skillsets to encompass Industry 4.0 methodologies and practices.

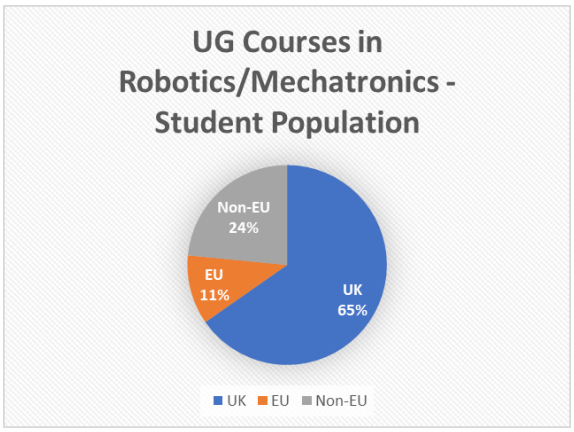
Specifically, development of a suite of Industry 4.0 focused CPD courses, delivered part time or full time over a short intensive period aimed at both technical staff and those operating in a managerial role within industry. A lifelong training programme is therefore desired which bridges the gap between academia and industry and which continuously adapts to industry demands whilst delivering state-of-the-art curricula. Typical pathways are depicted in Figure 14 and are shown here for completeness.



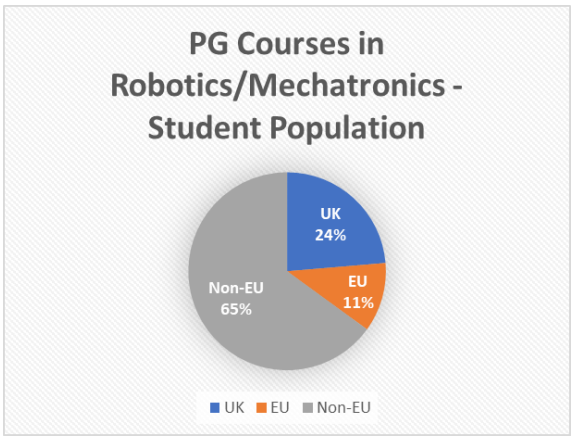
(a)



(b)



(c)



(d)

Figure 13. UK student population in terms of UG and PG numbers in Mechatronics and Robotics related programmes

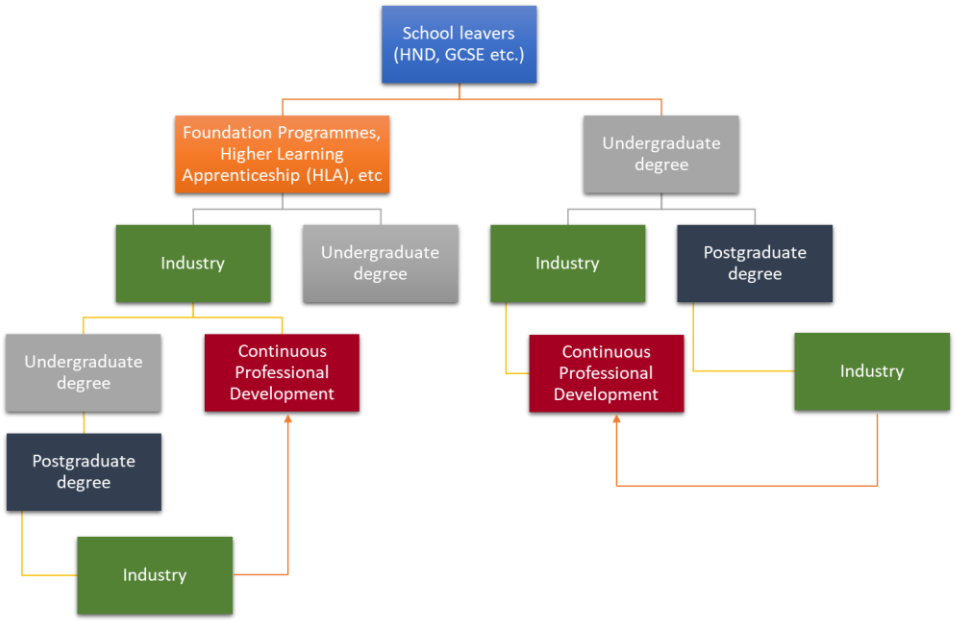


Figure 14. Typical lifelong training/learning pathways

6. Existing Collaborative Provisions Arrangements

Smart-Edu4.0 partner institutions have a number of existing ongoing collaborative arrangements which will form the basis of developing joint programmes between members of the consortium. These include foundation programmes, undergraduate, postgraduate including both study abroad and dual degree pathways. For example, QUB's partnership agreement with Shanghai University in China incudes study abroad (3+1+1 and 4+1) programmes whereas the partnership with Guangdong University of Technology is a 2+2 partnership which is a dual degree agreement. A full list of existing QUB partnerships is provided here[8]. Additionally, a list of all QUB's articulation arrangements is provided here. QUB and SERC already enjoys collaboration for some programmes such as BA Music and Audio Production and Foundation Degree in Early Childhood Studies. SERC also has a strategic partnership with Ulster University on a number of its foundation programmes including offering a foundation degree in Mechatronic Engineering which is highly relevant to Smart-Edu4.0.

A list of all collaborating partners for University of Limerick is provided here[9]. This includes UG, PG and Study Abroad partnerships with institutions from America to Middle East to Far East.

For NTUA in Greece, collaboration in UG and PG are in the form of student exchange programmes[10] at both UG and PG levels. A number of Schools have collaboration with universities across the UK and Europe such as Mechanical Engineering, Electrical and Computer Engineering and Mining and Metallurgical Engineering. A full list can be found here.

8 https://www.qub.ac.uk/directorates/AcademicStudentAffairs/AcademicAffairs/CollaborativeArrangements/TypesofCollaboration/InternationalPartnerships/RegisterofCurrentArrangements/

9 https://www.ul.ie/international/partnering-ul

10 https://www.ntua.gr/en/school/knowledge-without-frontiers

7. Conclusions

It is almost impossible not to get lost in all the available information surrounding Industry 4.0 and its associated topics and the fact that despite the buzz surrounding the fourth industrial revolution there is yet to emerge one unified model or standard that can be agreed upon. Manufacturing enterprises wishing to begin the digital transformation journey should think of it as just that; a journey with no clear destination or limits as it will have different meaning to each company and every individual within the workforce.

Before embarking on any process of implementation of Industry 4.0 methodologies, it is important that manufacturing enterprises are self-aware and carefully assess their own situation to ensure they are best placed to make effective use of Industry 4.0 practices and if not, decide on an optimal course to follow to achieve digital transformation. Enterprises need to consider whether there is a suitable understanding amongst its workforce of what Industry 4.0 is and why it will be beneficial to everyone in the workforce.

The initiatives and courses previously discussed could aid companies in at least deciding whether to pursue digital transformation or not. It may be the case that a company is not yet making full use of Industry 3.0 level automation, hence they could avail of training initiatives in this area first before tackling digital transformation. A continuous supply of trained individuals in industry 4.0 related topics is thus the ultimate long-term goal of the project.

It is envisaged that the topics discussed together with the findings within this document will stimulate further reading, learning, sharing, teaching and collaboration between the manufacturing industry and educational organisations with a view to develop industrially-relevant training initiatives in the journey towards the smart factories of the future.

Appendix A - List of Courses and Programmes offered in Ireland

Table 6. Cobotic Skillnet Training Courses

Course	Category	Location	Course length	Course Qualification
Industrial Electrical Systems Course L6	Technical Training -	Westmeath	5 Days	QQI Certification: 6N5377 (Fetac Level 6)
Industrial Electrical Systems – Hands-on course	Technical Training	Westmeath	3 days	QQI Certification: 6N5377 (Fetac Level 6)
Siemens S7 PLCs	Technical Training	Westmeath	3 days	
Introduction to Cobotics Technology Capabilities Interactive Training Programme	Technical Training	Westmeath	2 days	

Table 7. Polymer Training Skillnet training courses

Course	Venue	Duration
Mould Design - Online	Online	6 days
Equipment Validation Online	Online	4 days
Injection Moulding Module 1	First Polymer Training Skillnet	4 days
Troubleshooting Surface Defects in Injection Moulding	Online	3 days
Injection Moulding Module 2	First Polymer Training Skillnet	4 days
Design of Experiments (DOE)-Online	Online	6 days
Fundamentals of Injection Moulding - Online	Online	2 days
Injection Mould and Hot Runner Maintenance Online	Online	2 days
Plastic Part Design Online	Online	6 days
Plastic Material Selection Online	Online	8 days
Process Analysis and Control using Minitab - Online	Online	6 days
Injection Moulding for Quality Engineers Online Delivery	Online	3 days
Injection Mould Maintenance and Insert Care	Online	1 days
Injection Moulding Module 1	First Polymer Training Skillnet	4 days
Injection Moulding Module 1	First Polymer Training Skillnet	4 days
Plastics Materials & Processing for Medical Devices - Online	First Polymer Training Skillnet	7 days
Product and Process Validation Online	Online	10 days
Injection Moulding Module 2	First Polymer Training Skillnet	4 days
Design of Experiments (DOE)-Online	Online	6 days
Injection Moulding Module 3	First Polymer Training Skillnet	4 days
Equipment Validation Online	Online	4 days
Mould Design - Online	Online	6 days
Recycling Of Polymers - Online	Online	4 days
Injection Mould Maintenance and Insert Care	First Polymer Training Skillnet	1 days
Fundamentals of Injection Moulding - Online	Online	2 days
Injection Moulding for Quality Engineers Online Delivery	Online	3 days
Process Analysis and Control using Minitab - Online	Online	6 days
Plastic Material Selection Online	Online	8 days
Injection Moulding Module 2	First Polymer Training Skillnet	4 days
Injection Moulding Module 1	First Polymer Training Skillnet	4 days
Injection Mould and Hot Runner Maintenance Online	Online	2 days

Table 8. Irish Medtech Skillnet technical training courses

Course	Location	Course length
Additive Manufacturing for Medtech In Ireland	Westmeath	2 days
Advanced Machine Upskilling	Galway	10 days part time
Applied Continuous Improvement	Available nationally, based on demand	4 days
Computer Training	Clare, Cork, Dublin, Galway, Limerick Offaly, Roscommon, Westmeath	1 day
Computerised Production & Inspection Processes	Online	2 classes a week
Continuous Improvement in Manufacturing	Clare, Cork, Donegal, Limerick, Westmeath, Wexford, Online	2 days
Cyber-Physical Systems & IoT	Limerick, Online	1 month
Data Analytics & Machine Learning	Limerick, Online	9 weeks
Design for Medical Technologies	Limerick	15 days
Design Innovation for the Cardiovascular Sector	Galway, Online	2 days
Design of Experiments	Online	3 days
Digitalisation of Manufacturing in practice – MASTERCLASS	Online	4 days
Digitalisation of Production	Online	9 Weeks
Engineering Process Technician (JSSP)	Sligo	16 days
Executive Lean Awareness Training	Available nationally, based on demand	3 hours
Industrial Electrical Systems	Online	5 days
Industry-Hospital Innovation Partnership in Additive Manufacturing	Dublin	1 day
Lean Intensive Foundation Training	Available nationally, based on demand	1 day
Manufacturing Automation and Robotics	Limerick Online	7 weeks
Manufacturing Engineering Introduction	Galway	10 days
Manufacturing Operations for Life Sciences	Available nationally, based on demand	26 days
Masters of Engineering (MEng) in Digitalisation of Manufacturing	Limerick Online	2 Years
Medical Software Quality Assurance Programme (Job Seeker Programme)	Limerick	18 days
Medtech & Engineering Manufacturing Benchmarck Visit: BMW AND KUKA ROBOTICS, Germany.	Dublin	2 days
MÓR™ Benchmarking Model	Cork, Dublin, Galway, Kildare, Limerick, Longford	0.5 day
MTE Advanced Manufacturing Best Practice visit	Dublin	2 days
Siemens S7 Programable Logic Controller	Online	5 days
Total Knee Replacement Surgery	Dublin	1 day

Appendix B – List of Courses and Programmes offered in Greece

Table 9. UG Courses at Greek Institutions

Department	University	relevant courses	Category
School of Mechanical Engineering	National Technical University of Athens	Industrial Ergonomics Manufacturing Systems I Systems of Manufacturing processes II	Manufacturing
School of Mining and Metallurgical Engineering	National Technical University of Athens	Elements of Machining Automatic Process Control	Manufacturing, Sustainability aspects in Industry
School of Electrical and Computer Engineering	National Technical University of Athens	Industrial Electronics Sensors and Microsystems Technology Microelectronics: Fabrication of Integrated Circuits Sensors and Microsystems Technology Robotics I: Analysis - Control - Laboratory Robotics II: Intelligent Robotic Systems Intelligent Control in Robotics and Industry Virtual Reality, Haptics and Applications in Telerobotics	Industrial Electronics, Robotics, Industrial Internet of Things
Department of Industrial Design and Production Engineering	University of West Attica	Manufacturing of Specialized Products, Industrial Robotics Systems, Cyber-Physical Systems, Internet Of Things and Embedded Systems, Industrial Automation - PLC, Mechatronics, Design and Programming of Industrial Manufacturing Systems	Robotics Mechatronics Manufacturing
Department of Mechanical Engineering |	University of West Attica	Mechatronics	Mechatronics
School of Engineering: Department of Product and Systems Design Engineering	University of the Aegean	Mechatronics Robotics Studio 7B – Detailed Product Design I	Mechatronics Robotics
Department of Information and Communication Systems Engineering (ICSD)	University of the Aegean	Sensor Networks Robotic Control Internet of Things	Robotics Industrial Internet of Things
Home: School of Production Engineering & Management	Technical University of Crete	Mechatronics Robotics Manufacturing Technology I, Manufacturing Technology II Topics in Environmental Protection	Robotics Mechatronics Manufacturing Sustainability aspects in Industry
Department of Computer Engineering & Informatics	University of Patras	Intelligent Systems engineering & Robotics Robotics	Robotics

Department of Mechanical Engineering and Aeronautics	University of Patras	Computer Numerical Control (CNC) ROBOTICS	Robotics

Table 10. Postgraduate programmes in Industry 4.0

Program	University	Fees / Duration	Relevant Courses
Graduate Program in Mechatronics	University of Western Macedonia	3.000€ / 3 semesters / Part-time	Microcontrollers and Logic Programming, Industrial Robotics, Mechatronics Project Design (taught in Greek / English)
Automation Systems	National Technical University of Athens	For free / 3 semesters	Robotic Control Systems, Lab in Robotics, Mechatronic Systems, Sensors, Intelligent Control Systems and Robotics
Industrial Automation	University of West Attica	3.000 € / 3 semesters / Full or Part-time	Automation in Industrial Production / Mechatronics, Development of Innovative Automation Systems
Advanced Industrial & Manufacturing Systems	University of West Attica	3.500€ / 2 years / Part-time	Computer Integrated Product Development, Mechatronic Design and Automation (taught in Greek / English)
Internet of Things and Intelligent Environments	University of West Attica	2.100 € / 3 semesters / Full or Part-time	Embedded and Real-Time Systems, Internet of Things – Web of Things, Cyber-Physical Systems [CPS] and Smart Infrastructures, Industrial and Intelligent Control
Internet of Things: Intelligent Environments in Next-Generation Networks	University of the Aegean	3.000 € / 4 semesters / Full or Part-time	IoT Technologies and Applications, IoT Communication Technologies, Embedded Systems and IoT, Robotics and Computer Vision, Modern Networks and IoT Interfacing
Digital Culture, Smart Cities, IoT and Advanced Digital Technologies	University of Piraeus	3 semesters / Part-time	M2M Communications, Software and Applications for IoT
Robotics	International Hellenic University	2.400 € / 3 semesters / Part-time	Introduction to Robotics and Automation Systems, Autonomous Robotic Systems, Embedded Systems, Machine Intelligence