SURVEY OF CURRENT TRENDS IN MANUFACTURING ENGINEERING POSTGRADUATE PROGRAMMES IN THE UK

Trishel Gokool[1*] and Boppana V. Chowdary[2]
[1,2]Faculty of Engineering, The University of the West Indies, Trinidad
[1]Email: trishel.gokool@my.uwi.edu *(Corresponding author)
[2]Email: boppana.chowdary@sta.uwi.edu

Abstract: The promotion of innovation and current trends in the Manufacturing Engineering curriculum is essential to support the adoption and creation of advanced manufacturing technologies. However, the content and teaching methods employed by the engineering departments have long faced issues with incorporating industry needs and new developments into their various curricula. Manufacturing Engineering (MfgE) is no exception as there exists significant gaps between the MfgE curricula, latest advances in research and current industrial practices in Trinidad and Tobago (TT). The present paper investigates the trends in postgraduate programmes in the United Kingdom (UK) in the area of MfgE. It highlights the current curricula structure and content of universities in a developed region with a similar education system to TT with the aim of identifying key areas of MfgE focus. The study reveals that UK universities balance soft skills with technical learning, as research skills, management, manufacturing systems, systems simulation and, design and innovation are the top course themes. Moreover, there exists significant collaborative efforts between UK universities, industry and the government which drives research and development of emerging technologies. The findings of this study will be useful as a benchmarking tool for improving the TT MfgE curriculum in the future.

Keywords: *Curriculum, Education, Manufacturing, Engineering, Trends, United Kingdom*

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1. Introduction

Manufacturing has shown to be an effective economic growth strategy at the early stages of a country's development but the effect on this growth critically depends on the skills and education of the human capital [1]. Manufacturing Engineering (MfgE), like that of other engineering fields, have long faced issues with incorporating industry needs and new developments into its educational curricula. This is evident in MfgE programmes in Trinidad and Tobago (TT)'s universities, namely The University of the West Indies and the University of Trinidad and Tobago, as most of the MfgE modules in their undergraduate and graduate programmes have remained static over the years. According to [2], manufacturing is an ever expanding field which never

restricts itself to current practices but eagerly uses the latest scientific findings to develop more reliable and profitable industries. Hence, finding the right balance between future and current but soon to be obsolete topics within a short timeframe is a significant challenge. Moreover, the mere act of swapping outdated courses for modern topics or adding new courses to a programme is also challenging as substantial justification is required, with most curriculum committees lacking data sources for guidance on decisions and validations [3].

This paper considers the curricula of MfgE postgraduate programmes in the United Kingdom (UK) for use as a benchmark for later MfgE education research. The UK was selected based on the similarities between its educational system and that of TT, as well as the fact that the UK is a developed country and has made significant contributions to the manufacturing field. A survey was performed on the current MfgE curriculum in the UK to determine the general trends in curricula content and identify the topics that are covered in various curricula. The paper also briefly discusses the collaborative research efforts in selected universities and the potential applications to the local curriculum improvement. The outline of the paper is as follows: section 2 describes the research methodology employed in the study, section 3 presents and analyses the results of the curricula survey and section 4 concludes the paper.

2. Research Methodology

In the UK higher education system, much like the TT higher education system, a credits structure is utilised to show the progress of students in relation to their degree completion. For each degree programme, a student must complete a predefined total number of credits, with each course having an allotted number of credits. Moreover, there are stipulations regarding the types of courses that students may take. In graduate engineering programmes, most courses are categorised as compulsory which are core programme requirements that must be completed, or elective, speciality areas that can be chosen by the student.

The raw data was collected from the Engineering Council's Accredited Course Search (ACAD) database, which holds details of all accredited degree programmes that partially or fully satisfy the education requirement for Incorporated Engineer (IEng) and Chartered Engineer (CEng) registration. The following search criteria was employed:

- Award: MSc
- Accredited for: CEng
- Entry year: Any
- Provider Type: Any
- PEI Ref: Any
- Keywords in title: Manufacturing
- Location: United Kingdom
- Course Type: Fulltime, Sandwich, Part-time, Distance learning

In collecting and analysing the curricula data for each of the search results, the most recent course descriptions were downloaded from the university websites. Moreover, in order to compare the curricula effectively, categories were defined to map the individual courses as the course titles of various universities may not correspond to each other. Table 1 shows the course categories that were used in the analysis. A frequency analysis was performed on the curricula of the resulting

universities in order to determine the trends in the course contents. The structure of the programmes were also considered as well as the research activities of several of the surveyed universities.

Table 1: Taxonomy of each category of Manufacturing Engineering course

Category	Topics/description
Computational modelling	Computer-aided engineering, FEA, Computational engineering modelling, CFD
Design	Engineering Design, Product Modelling, Innovation, New Product Development
Systems Simulation	Systems Modelling and Simulation, Resources Simulation, Operations Management, Modelling and Optimisation, Process Improvement, Virtual Systems Design
Industry 4.0	Big data analytics, Data mining, Industry 4.0, Enterprise Systems
Manufacturing Systems	Manufacturing Systems, Lean Manufacturing, Agile Manufacturing
Sustainable Eng.	Sustainable Design, Green Engineering, Sustainable Development, Sustainable Energy Management, Environmental Risk
Robotics	Robotics, Automation, Mechatronic systems
Additive Manufacturing	Additive Manufacturing, Prototyping
Advanced Materials	Composites, Applied Materials, Biomaterials, Materials Technology, Coatings, Tribology
Advanced Man. Processes	Advanced Manufacturing Processes, Advanced Welding Processes, Laser Materials Processing, Global Manufacturing, Technology
Metrology	Advanced Measurement Systems and Data Analysis, Metrology, Measurement Science
Advanced Machining	Machining, Advanced CAD/CAM
Precision Engineering	Nanotechnology, Precision Engineering, Micro Devices
Quality	Quality Management, TQM, Reliability
Project Management	Project Management, Financial Control
Supply Chain	Logistics, Supply Chain Management
Advanced Mechanics	Vibrations, Acoustics, Tribology, Dynamics, Fluid Mechanics, Thermofluids
Management	Managing People, General Management, Entrepreneurship, Business Studies, Strategic Management, Enterprise Studies
Research Skills	Research Methods, Technical Writing, Experimental Methods

3. Results and Analysis

The following subsections analyse the graduate Manufacturing Engineering programmes in the UK by examining their curriculum structures as well as the main course themes. Moreover, the research and collaborative efforts of some of the investigated universities are discussed with possible implications for universities located in Trinidad and Tobago.

3.1 Curricula Structures

Table 2 summaries the structure of each MfgE programme available at the various UK universities. It can be observed that a few universities including Cranfield University, Kingston University and University of Derby, offer multiple MfgE graduate programmes that focus on different areas of

MfgE, as the field is relatively large, and students and industry may require a more specialised focus. Moreover, the duration and number of courses vary significantly. Most programmes span one year full-time (80%) and consist of eight courses (47%). However, some programmes span up to 18 months full-time and can comprise as little as four (4) or as much as nine (9) courses. More than half of the universities investigated also have no elective courses, requiring the students to undertake all of the listed courses. This curriculum structure allows students to get a broad understanding of many core topics in the MfgE field but prevents them from tailoring their programme according to their interests. Moreover, the Institution of Mechanical Engineers (IMechE) is recognised as the most popular accreditation standard for UK universities and London and Manchester are the most popular regions for MfgE graduate programmes. Furthermore, all programmes require students to successfully complete an individual project or dissertation that allows them to undertake research in a specialised field of study.

Table 2: Basic curriculum structure of each Master of Science Manufacturing Engineering programme

University	Programme	Duration	No. of Courses	Accreditation
Brunel University, London, UK	Advanced Manufacturing Systems	1-year full-time; 3-5 years distance-learning	6 compulsory; 2 electives (chosen out of 6)	IMechE
Cranfield University, Cranfield, UK	Engineering and Management of Manufacturing Systems	1 year full-time; 2-5 years part-time	8 compulsory	Institution of Engineering & Technology (IET), Royal Aeronautical Society (RAeS) and IMechE
	Manufacturing Technology and Management		3 compulsory; 5 electives (chosen out of 13)	Institute of Materials, Minerals & Mining (IOM3)
Kingston University, London, UK	Advanced Industrial & Manufacturing Systems Masters	1 year full-time (2 years with placement); 2 years part-time	4 compulsory; 1 elective (chosen out of 3)	IMechE
	Advanced Product Design Engineering Masters & Manufacturing			

Loughborough University, Loughborough, UK	Advanced Manufacturing Engineering and Management	1 year full-time; 2-8 years part-time	6 compulsory	IMechE and IET
Manchester Metropolitan University, Manchester, UK	Mechanical Smart Systems Engineering	1 year full-time	8 compulsory	
University of Manchester, Manchester, UK	Advanced Manufacturing Technology & Systems Management	1 year full-time	8 compulsory	IMechE
University of Bradford, UK	Advanced Mechanical Engineering	12-15 months full-time	3 compulsory; 3 electives (chosen out of 6)	IMechE
University of Derby, Derby, UK	Advanced Materials and Additive Manufacturing	1 year full-time; 2-3 years part-time	5 compulsory; 4 optional	IOM3
	Mechanical and Manufacturing Engineering		7 compulsory	IMechE
University of Greenwich, London, UK	Mechanical and Manufacturing Engineering	1 year full-time; 2 years part-time	8 compulsory	IET
University of Hertfordshire, Hatfield, UK	Manufacturing Management	12- 18 months fulltime, 3 years part-time	8 compulsory	Institute of Manufacturing (IManf)
University of Liverpool, Liverpool, UK	Advanced Manufacturing Systems and Technology	1 year fulltime	9 compulsory for non-UK students; 8 compulsory and 1 elective (chosen out of 7) for UK students	IMechE

University of Portsmouth, Portsmouth, UK	Advanced Manufacturing Technology	12-16 months full-time; 3 years part-time	6 compulsory	IMechE

3.2 Main Course Themes and Trends

The main course themes for UK manufacturing engineering graduate programmes, as observed in Fig. 1, are Research skills, Management, Manufacturing systems, Systems simulation and Design and innovation. Research skills and Management are commonly referred to as "soft skills" that enable graduates to effectively manage their own research projects as well as teams, skills that will be practical in the workplace environment. The other main themes are core manufacturing areas that enable graduates to analyse and create solutions to industry problems by way of design, modelling, simulation, and manufacturing optimization strategies. Themes that are less common include Advanced Mechanical Engineering, Metrology and Industry 4.0. Although many students pursuing Master's degrees in Manufacturing Engineering have a background in mechanical engineering, many universities do not feel the need to include core Mechanical Engineering topics in their programmes. Metrology, which explores industrial quality control measurements and calibration, is also remarkably uncommon. Industry 4.0 is currently taking the world by storm, as it denotes the 4th Industrial Revolution led by the top institutions in Europe. However, many UK graduate programmes have yet to include this significant area in their curriculum.

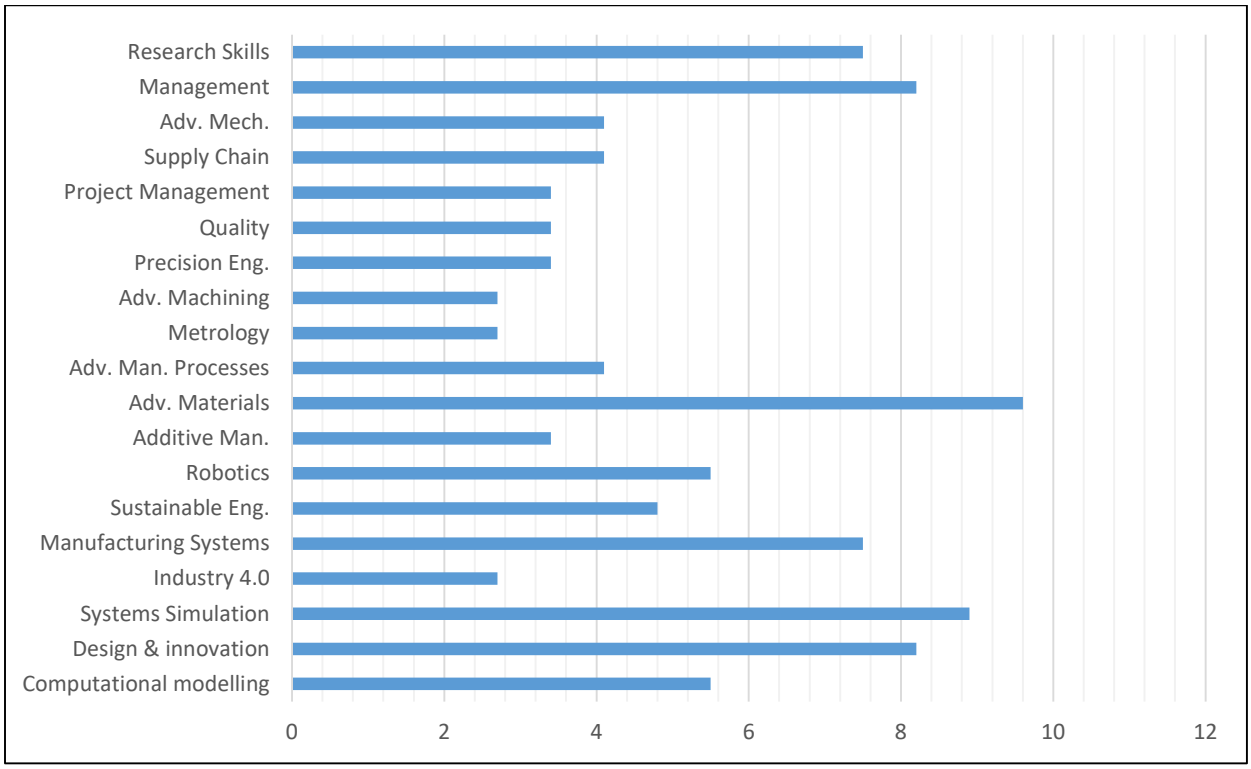

Figure 1: Frequency of course categories amongst the Master of Science Manufacturing Engineering programmes

The collected information was used to map compulsory or core courses and elective courses to the categories outlined in Table 1, as shown in Fig. 2. According to the programme structure and focus, multiple courses in a single programme could be mapped to the same category, whilst in other cases a single course could be mapped to multiple categories. The latter case occurred because some courses spanned several topics that are generally seen to be dissimilar, such as the "Robotics, Metrology and Bioengineering" course offered by the University of Manchester. It is observed that Manufacturing systems, Research skills and Advanced machining courses were only offered as compulsory courses, whilst Precision engineering was only offered as an elective. Based on the distribution of compulsory versus elective courses, it can be deduced that the most significant MfgE course categories of UK MSc. programmes are Computational modelling, Design, System simulation, Manufacturing systems, Robotics, Advanced machining, Management and Research skills.

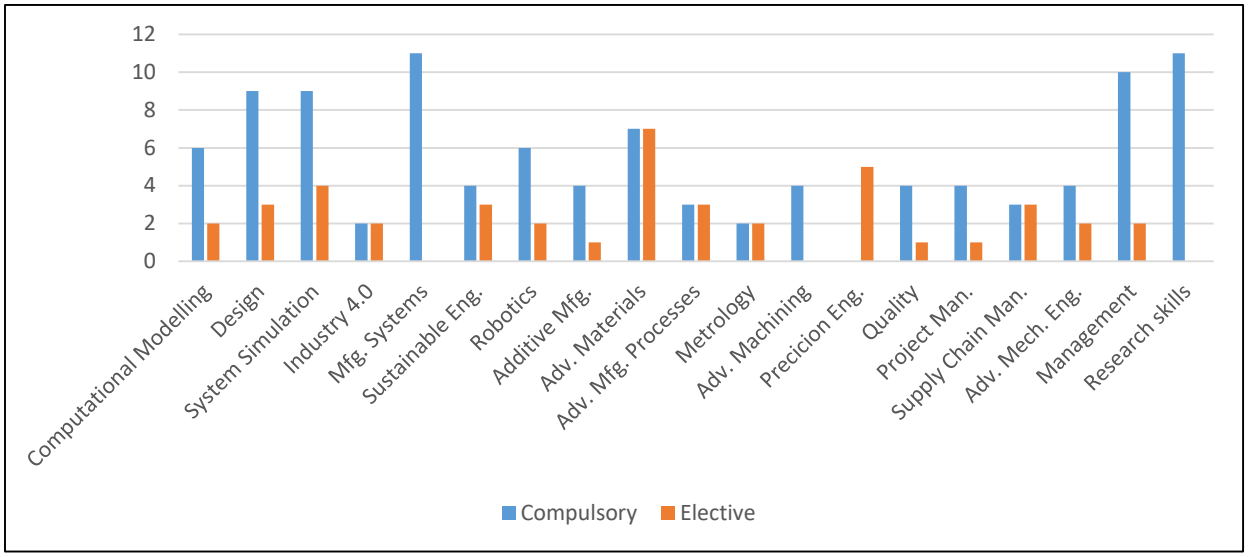

Figure 2: Compulsory versus elective course categories

3.3 Research and Collaboration

A notable attribute of the UK graduate MfgE curricula is the funding support provided by the UK government, European Union (EU), industries and UK charities [4]. Universities can therefore feature state of the art laboratories that perform cutting edge research in areas such as advanced materials, manufacturing sustainability, CAD, 3D printing and many others. This also allows the curricula of taught graduate programmes to be guided by leading research, therefore keeping the curricula current and industrially relevant. Universities in TT would do well to adopt such an approach to curriculum refinement whereby the university supports the manufacturing industry through collaborative research which in turn supports the engineering curricula, with the government providing supplemental funding. The following paragraphs highlight a few notable research strategies of select universities.

The University of Manchester houses three business innovation centres that undertake approximately £420 million worth of world leading research. These include the National Graphene Centre, the Graphene Engineering Innovation Centre, The Henry Royce Institute and the BP International Centre for Advanced Materials. The university is currently acting to become the hub of Industry 4.0 in the UK and launched its Industry 4.0 Vision and Strategy in April 2019 [5]. This

strategy aims at positioning the university as a translational hub that facilitates partnership with industry and supports lab-to-market solutions, thus transforming them into centres of both academic and industrial innovation to further the UK's manufacturing industry.

Loughborough University hosts two of the UK's National Engineering and Physical Sciences Research Council (EPSRC) Centres for Innovative Manufacturing (CIM) and are partners in another three CIMs [6]. The research themes include sustainable manufacturing, additive manufacturing, healthcare engineering and electronics manufacturing. Moreover, the university leads two EPSRC Centres for Doctoral Training. Research is funded by the UK Research Councils and industrial collaborations ensure that the university works on 'live' projects to support their local manufacturing industry.

Another prominent university that engages in manufacturing research is the University of Cambridge which established the Institute of Manufacturing (IfM). This institute embarks on research and consultancy to aid companies and governments in innovating their products and services in order to provide social and economic benefits [7]. The main areas of research include new materials, and production technologies, digital manufacturing technologies, data analytics and business development. The profits of the IfM are used to fund future research at the University. The IfM also offers a one year MPhil in Industrial Systems, Manufacture and Management, which comprises of taught modules that span production processes, operations management, supply chain management, data and simulation, marketing, strategy, product delivery and industrial economics, company visits and in-company projects, enabling students to gain direct experience in solving challenges in various manufacturing sub-sectors.

In Trinidad and Tobago, the government and industry have done poorly to establish mutually beneficial collaborative research with universities. However, as observed in the UK, collaboration and trust is required to propel the manufacturing industry forward, as no one entity, government, industry or university, can function alone to effect change.

4. Concluding Remarks

In this paper, a brief survey was performed on UK graduate manufacturing engineering programmes to determine the main course themes and curricula structures and highlight the research undertakings of selected universities. The Engineering Council's Accredited Course Search (ACAD) database was utilised to search for accredited UK Master of Science programmes in the field of manufacturing that were accredited to the CEng level. A total of 15 programmes offered by 12 universities were found. The course themes of these programmes reveal that both soft skills courses such as research methods and management, and core manufacturing topics like manufacturing systems, systems simulation and design and innovation, are dominant. Emerging fields like Industry 4.0 are taught in only a few programmes, but this is expected to increase with the development and popularity of these fields. The results of this study are meant to be used as a benchmarking tool for improving the TT MfgE curriculum. In that regard, the UK is a good benchmark to compare local programmes as most local manufacturing programmes are accredited by UK based professional boards. Moreover, it was reported that many UK universities have state of the art laboratories that perform leading research funded by the UK government, EU, industries and UK charities. Apart from generating supporting income, this cutting-edge research guides the curricula of taught graduate programmes making them current and relevant to the UK industry. Trinidad and Tobago should try to follow this approach whereby various stakeholders fund

university led collaborative research that have a direct focus on the current and future needs on industry and diversification. Further research along these lines is planned.

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