Development of M.Eng. Programs with a Focus on Industry 4.0 and Smart Systems

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Abstract. Master of Engineering Programs are often designed to provide skills that can be readily used in industry. Although many M.Eng. Programs include courses that can be selected from an existing pool of traditional engineering topics to fulfill various specializations, this paper describes the development of new M.Eng. Programs designed to include courses that address the new trends in industry. This paper presents the design and implementation of new M.Eng. Programs that focus on modern approaches in manufacturing; namely Industry 4.0 and Smart Systems. The integration of these new M.Eng. Programs with related undergraduate programs are also described, as is the potential to provide certain students with an accelerated pathway to professional licensure. Several common elements of Industry 4.0 trends are contained within these new programs. These elements include cyber-physical systems, internet of things, and development of smart systems. This paper presents the development of three M.Eng. Programs: Automotive, Automation, and Advanced Manufacturing. These programs focus on real-world problems of industries in which progress is fast and in which specialists need to provide constantly evolving, creative, and innovative solutions. Being designed for both to full-time students and part time students from industry, the courses developed for these programs are offered in the evening. Students can chose between a coure-and-project option that includes 6 courses and a project and a course-only option that include eight course. The graduates of these programs are expected to have a strong technical grounding with broad management and industry perspectives combined with strong nontechnical areas of expertise.

Keywords: M.Eng. · Industry 4.0 · Smart systems · McMaster

1 Introduction and Background

The W Booth School of Engineering Practice and Technology (SEPT) at McMaster University in Hamilton, Ontario, Canada is a School contained within the Faculty of Engineering. SEPT offers seven undergraduate programs which award Bachelor of Technology (B.Tech.) degrees. The School also offers five specialized Masters programs awarding M.Eng. degrees. The defining characteristic of the School is its focus on real-world problems. SEPT exists as a complement and a contrast to the traditional Departments within the Faculty of Engineering which focus on theory and discovery and award

M.E. Auer and D.G. Zutin (eds.), *Online Engineering & Internet of Things*,
Lecture Notes in Networks and Systems 22, DOI 10.1007/978-3-319-64352-6_7

Bachelor of Engineering (B.Eng.) degrees, Master of Applied Science (M.ASc.) degrees and Doctorate (Ph.D.) degrees.

The undergraduate programs in SEPT differ from traditional Bachelor of Engineering Programs in several ways. Some advantages of the programs are: they are strongly influenced by industry and their curriculums are flexible, they focus more on experiential learning and student-centered learning, they employ more sessional/industry instructors, and they integrate the fundamentals of business into the curriculum. One disadvantage of the programs is that they are not 'accredited' by the governing body that oversees engineering curricula in Canada. Graduates of these programs have a more difficult, pathway to professional licensure than graduates of traditional Bachelor of Engineering programs.

Of the seven undergraduate programs in SEPT, four of them are "degree completion programs" (DCP). These are designed for graduates of post-secondary institutions called "colleges of applied arts and technology" or colleges for short. McMaster University's degree completion programs offer a Bachelor of Technology degree upon the completion of 24 courses above and beyond the completion of a three-year college diploma in a related field. The four DCP programs are: Civil Engineering Infrastructure Technology, Energy Engineering Technologies, Manufacturing Engineering Technology, and Software Engineering Technology. Each program contains 17 technical courses and 7 business/management courses. These programs also contain a mandatory 8-month co-op work term, although this requirement is waived for the majority of students since the program's unique evening and weekend schedules attract a large number of working students. There are currently 400 students in the DCP programs, the majority are enrolled as part-time students.

The three remaining undergraduate programs in SEPT are Automotive and Vehicle Technology, Process Automation Technology, and Biotechnology. These programs are direct-entry from High School and are 4.5-year degrees which include 12-months of co-op work placement. These programs are offered during regular daytime hours and are full-time programs. There are currently 800 students enrolled in these programs.

At the graduate level, the School of Engineering Practice and Technology offers five unique Masters programs–four granting the degree Master of Engineering, and one granting the degree Master of Technology. These programs are: Master of Engineering Entrepreneurship and Innovation, Master of Technology Entrepreneurship and Innovation (open to students with non-engineering/non-science undergraduate degrees), Master of Engineering Design, Master of Engineering and Public Policy, and Master of Engineering in Manufacturing Engineering. There are currently 150 students enrolled in these programs.

The expansion of the Master of Engineering in Manufacturing Engineering into three 'Industry 4.0 and Smart Systems' focus-areas forms the subject of this paper. The three new M.Eng. focus-areas are: Automation, Automotive, and Advanced Manufacturing.

2 Motivation

The School of Engineering Practice and Technology is well positioned to prepare graduates for employment in the manufacturing sector. The School's location in Hamilton, Ontario is central to Canada's manufacturing industry.

Producing university graduates with skills that are immediately applicable is a challenge in many industries with rapidly-changing technology, and this is especially true in the manufacturing industry [1]. It is particularly evident in the area of automotive engineering [2]. SEPT has already implemented undergraduate programs that address this challenge; namely Automotive and Vehicle Technology, Process Automation Technology, and Manufacturing Engineering Technology. Industry 4.0-based Master's Programs will provide students with a continuing pathway to graduate-level programs. It is also intended to facilitate the pathway to professional licensure for graduates of the aforementioned undergraduate programs, but is also open to graduates of traditional undergraduate engineering programs as well as international students. The pathways created by the new M.Eng. programs are shown in Fig. 1.

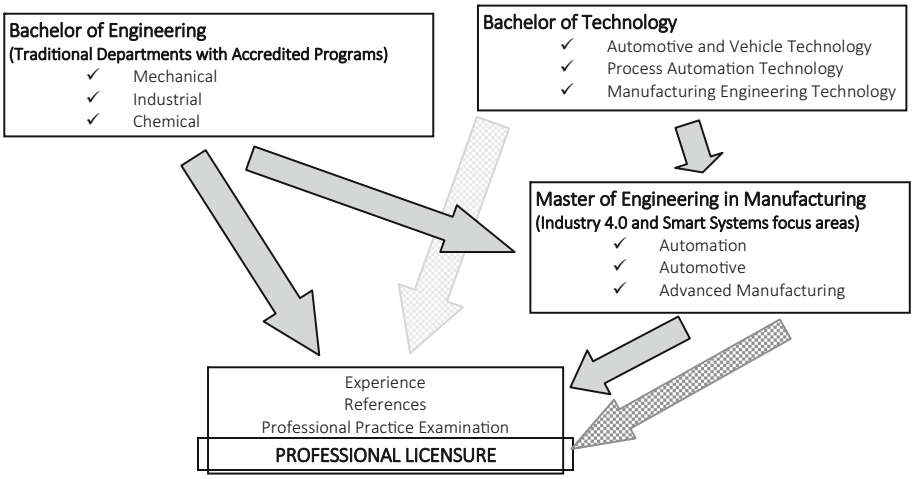

Fig. 1. Pathways

It should be noted that graduates of the Bachelor of Technology undergraduate program have an existing pathway to professional licensure (shown by the *light*-grey patterned arrow in Fig. 1) but this involves a series of technical challenge exams administered by the Provincial license-granting body. The number of exams can range from as few as four, to as many as ten depending on the year of graduation. More recent graduates are assigned fewer exams thanks to the evolution of the curriculum towards content that is more favorable to the licensing body. Completion of an M.Eng. degree after the B.Tech. degree can significantly reduce or in some special cases even eliminate the need to complete any challenge exams (represented by the *dark*-grey patterned arrow). Additionally, the time spent in the M.Eng. program may also count towards the

amount of work experience required for licensure. Typically, the M.Eng. program will count as 1-year of the required 4-years of work experience.

The new M.Eng. Programs within the School of Engineering Practice and Technology have content and delivery methods consistent with the Vision of the new school. The School's Vision can be characterized by the following elements: industry-driven, hands-on, case-studies, in course projects, advanced methods and technologies, innovative teaching methods, sustainability, community-focused, professional development, communications, management, design, problem-solving, and integration of professional and technical skills.

With this Vision in mind the motivation for introducing these three new focus areas to the Master of Engineering in Manufacturing Engineering (MEME) can be organized into four main areas:

1. Opportunities for Students
2. Opportunities for Faculty
3. Opportunities for Partners
4. Opportunities for the Faculty of Engineering.

The creation of the new M.Eng. programs also provides the School with an opportunity to educate students in areas that are complementary to the technical aspects of Industry 4.0. Successful Industry 4.0 implementation involves aspects of a business 'outside' the functions related directly to the manufacturing process. Business considerations such as human resource management, accounting and finance, strategy, culture, and leadership all play a role in the successful implementation of Industry 4.0. This supports the idea of a T-Shaped graduate, with a broad knowledge of business that is outside their specific technical area [3]. This concept is particularly important in the area of human resource management and supply-chain management [4, 5].

2.1 Opportunities for Students

These new focus areas within the M.Eng. Programs in the W Booth School of Engineering Practice and Technology create the following opportunities for students:

- The chance to obtain a graduate degree in a high-demand, industry driven topic.
- Pathways to the new M.Eng. in Manufacturing Engineering (MEME) focus areas can be streamlined by adding undergraduate elective courses that offer advanced credit for M.Eng. programs.
- Undergraduate and Graduate students will connect inside the courses that are offered for advance credit. This offers the potential for mentoring, and possibly even collaboration on projects.
- Graduate students will have the opportunity to become Teaching Assistants for the Undergraduate courses.
- Undergraduate students may have increased contact with industry partners engaged in projects with Masters students. Possible co-op placement opportunities for undergraduate students may result.

- A clear pathway into a Master's program will offer Bachelor of Technology graduates an improved pathway to professional licensure.
- Completing an M.Eng. degree offers Bachelor of Technology graduates the opportunity to participate in the Ritual of the Calling of the Engineer (the 'Iron-Ring').
- The new focus areas will remain accessible to graduates of more traditional Bachelor of Engineering programs, both from McMaster and elsewhere.

2.2 Opportunities for Faculty

It should be noted that the undergraduate programs in SEPT employ a large number of contract faculty and teaching-track faculty. These faculty members have heavy teaching loads and are often responsible for teaching most of the core and entry-level courses. These new focus areas within the M.Eng. programs in the W Booth School of Engineering Practice and Technology create the following opportunities for the undergraduate faculty members:

- Opportunities to teach and mentor graduate students
- Opportunity to teach graduate level courses in their own areas of expertise
- Chance for collaborative applied research, innovation in teaching and learning, and pedagogical research.

Faculty already teaching in the existing five M.Eng. programs may see the following opportunities:

- Synergy of people with common interests
- More effective use of human resources and less reliance on sessional lecturers
- Possibility to share resources: building (labs, room bookings, meeting rooms) and technical support staff.

Additionally, there are 'research gaps' between current manufacturing systems and the potential that exists with the implementation of industry 4.0 ideas. This supports the idea for educational programs designed specifically around an Industry 4.0 framework and creates the potential for research opportunities for Faculty involved in these new focus areas [5].

2.3 Opportunities for Partners

These new focus areas within the M.Eng. Programs in the W Booth School of Engineering Practice and Technology create the following opportunities for the School's partners:

- Feeder colleges to the DCP programs can offer students a direct pathway from college through to an M.Eng. degree, and ultimately to professional licensure
- Community Partners (Companies, Organizations, and Government):
  - Richer engagement with groups of undergraduate and graduate students
  - Working with a broader spectrum of potential co-op or full-time employees prescreened through project engagement.

2.4 Opportunities for Faculty of Engineering

- Growth in enrollment at both the undergraduate and graduate levels
- Ability to deliver specialized M.Eng. programs not currently offered in the traditional engineering Departments
- The expansion of an already effective School focused on depth and breadth of learning, pedagogical research, and engineering practice
- Expanding programs committed to serving community and industry needs
- Flexibility to offer undergraduate and graduate curriculum that responds quickly to changes in community and industry needs (unlike accredited programs)
- Enhanced recognition and reputation of the Faculty
- Further the Faculty's mission to implement the concept of sustainability into the curriculum of all programs - embedding sustainability into the new M.Eng. focus-areas is important in light of the great opportunities that exist in the area of Industry 4.0 [6].

An opportunity for the Faculty, and in particular the School of Engineering Practice and Technology, is the opportunity to create a special teaching/learning/research facility called a 'Learning Factory'. This small-scale 'functioning' manufacturing facility offers a chance for smaller companies to train employees in the skills and technology needed to implement Industry 4.0 concepts. It also positions the university as a direct supporter of local/regional companies through technology as well as providing a supply of appropriately trained professionals [7].

3 Methodology

The activities described in this section were carried out by a SEPT committee called the M.Eng. Task Force. This group of six SEPT faculty members, plus 1 representative from the School of Graduate Studies, carried out monthly meetings from approximately mid-2015 to mid-2016. This section outlines the committee's activities.

3.1 Market Research

The first step in the development of the new M.Eng. focus areas was to engage students and alumni in market research. The results of a survey that included responses from 354 B.Tech. students, 342 B.Eng. students, and 146 alumni are shown below. A study of competing programs at nearby Universities was also completed.

- B.Tech. Students–50% indicated a desire to pursue an M.Eng. degree
- B.Eng. Students–more than 80% indicated a strong interest in an M.Eng. degree
- Alumni–approximately 66% of McMaster Engineering Alumni living within a 1-hour commute of McMaster indicated a strong interest in an M.Eng. degree
- M.Eng. programs at other Ontario Universities are popular; even 'over-subscribed'
- Based on historical enrollment numbers in the existing M.Eng. programs, there is typically a large demand from international students (>60% of existing M.Eng. students are international students).

Based on the results of the market research, it was evident that the demand for M.Eng. programs was strong among all target groups. This market research encouraged the M.Eng. Task Force to continue its activities.

3.2 Implementation

To facilitate a January 2017 implementation of the new Master of Engineering in Manufacturing Engineering (MEME) focus areas, the new focus areas needed to be structured within the framework of the existing program. It was not possible to seek approval for a completely new program structure as this could take up to 2-years. The existing framework for the MEME program was as follows:

- Students can take up to two graduate level courses from the Mechanical, Materials, and Chemical Engineering Departments.
- Each student must complete a project at a manufacturing company plus six graduate level courses (or 8-graduate level courses *without* a project).
- Courses from Departments other than the three 'approved' Departments (Mechanical, Materials, and Chemical) must be approved on a case by case basis.
- All other courses must be taken within SEPT.

The details of the implementation suggested that it was possible to offer the new MEME focus-areas for students starting the program in January 2017 provided they elected to complete the 6-course plus project option. The 8-course option would need to be implemented in the Fall of 2017 due to the requirement to create and seek approval for additional (new) courses within SEPT.

Table 1. Actual course-offerings ('core' and 'elective')

	Automation	Automotive	Advanced manufacturing
Industry 4.0	**C**	**C**	**C**
Components, networks, interoperability	**C**	**E**	**C**
Sensors and actuators	**C**	**C**	**C**
Data mining & machine learning	**E**	**E**	**E**
Cyber security	**E**	**E**	**E**
Systems analysis and optimization	**E**	**C**	
Hybrid & electric vehicles design		**E**	**C**
Additive manufacturing		**C**	**E**
Robotics	**E**	**E**	**E**
Analysis & troubleshooting of Mfg operations	**C**	**C**	**E**
Real time control, advanced topics	**C**	**E**	**E**

Other actions undertaken by the M.Eng. Task Force included:

- Preparation of an expanded list of pre-approved graduate level courses from Departments other than the three approved Departments (Mechanical, Materials, Chemical).
- Approval to offer a selected number of SEPT undergraduate courses as possible 'advance-credit' courses.
- Design and approval for new SEPT Industry 4.0-themed courses for inclusion in the Fall 2017 program start (see Table 1).

3.3 Final Program Design

- Students will be required to take 8-courses
- Students may opt for 6-courses plus a project (project subject to approval)
- Full-time and part-time studies will be possible; courses delivered in the evenings when possible
- Some online course-offerings will be considered.

3.4 Future Developments

The launch of a fourth Industry 4.0 focus area is targeted for September 2018. This focus area would be in 'Digital Solutions'.

A second M.Eng. theme-area tentatively referred to as 'Smart Cities' is also targeted for September 2018. Specializations may include: Civil Infrastructure, Biotechnology, and Power and Energy.

4 Summary and Conclusions

A set of M.Eng. Programs developed at McMaster University in the School of Engineering Practice and Technology with a focus on modern real-world problems from industry and society are expected to produce graduates well positioned for careers on the leading edge of manufacturing engineering and technology.

The new M.Eng Programs are innovative, interdisciplinary, industry-focused, and have a strong focus on management, leadership, and community engagement. They have strong industry interaction and include projects meaningful to society. The new Programs also complement the associated undergraduate programs in manufacturing, software, process automation, and automotive and vehicle technology, yet remain accessible to graduates of more traditional engineering disciplines.

Although implementations of Industry 4.0 key elements can vary significantly within different specializations, there are several common elements. These include cyber-physical systems, internet of things, and development of smart systems. This paper presented the development of three M.Eng. Programs that include these elements: Automotive, Automation, and Advanced Manufacturing. These programs focus on real-world problems of industries in which progress is very fast and in which specialists need to provide constantly evolving, creative, and innovative solutions. The M.Eng. programs

offer full-time and part-time options, as well as course-and-project or course-only options.

The graduates of these programs are expected to have a strong technical grounding with broad management and industry perspectives combined with strong nontechnical areas of expertise.

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