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Curriculum Reform in Manufacturing Education at the University of Calgary*

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In this paper, we describe the impact of a campus-wide curriculum redesign initiative at the University of Calgary on our recently developed undergraduate program in manufacturing engineering. This program had its beginnings in the 1980s and was fully established in 1995. We describe the curriculum, which has a foundation in general manufacturing fundamentals and satisfies the academic requirements for registration as professional engineers in Canada. We then focus on the analysis of the existing curriculum, and based on this analysis, offer our plan for future curriculum reform.

INTRODUCTION

IN RECOGNITION of local industry's need for highly skilled engineers who can bring innovative solutions to the manufacturing sector, the Department of Mechanical and Manufacturing Engineering at the University of Calgary introduced manufacturing into its curriculum. This was first in the form of a minor program in Computer-Integrated Manufacturing (CIM) in 1989, then as a full B.Sc. in Manufacturing Engineering in 1995.

Like all engineering programs in Canada, the B.Sc. in Manufacturing Engineering is designed to meet the requirements of the Canadian Engineering Accreditation Board (CEAB) (CCPE, 2002). This ensures that there is a strong foundation in mathematics and basic sciences, a broad preparation in engineering sciences and engineering design, as well as exposure to non-technical subjects in the humanities, social sciences, arts, management, engineering economics and communication.

Shortly after the development and introduction of this new curriculum, however, the university embarked on a series of unique campus-wide program-level projects aimed at curriculum innovation with the strategic goal of producing students who have 'a coherent range of knowledge, intellectual capabilities, human skills, attitudes and values that are essential for successful personal and professional lives' (University of Calgary, 1996). Central to this goal are seven key features that should be a part of all undergraduate programs at the University of Calgary:

1. A clearly identifiable field of study.
2. A defined interdisciplinary component.
3. An international component.
4. An experiential learning component relevant to the program objectives.
5. Provision for broad and extended faculty-student interaction at the program level.
6. Integration of research.
7. An explicit program syllabus, which sets out in advance the knowledge and skills to be acquired in a program of study.

This university-wide initiative required us to embark on a curriculum reform process that involved integrating the university's broad strategic requirements with the already stringent requirements of the CEAB.

To respond to this strategic initiative, the author has been involved in the curriculum redesign process for the B.Sc. in Manufacturing Engineering that involves determining the extent to which the program is already aligned with the University's strategic direction, where changes must occur, and finally implementation of these changes.

This paper focuses on the creation of an 'initial explicit syllabus' for the current curriculum as well as the analysis of the syllabus in the context of the university's curriculum redesign initiative and the CEAB requirements. The initial explicit syllabus for the B.Sc. in Manufacturing Engineering looks in detail at the objectives of the various learning processes in the program, the types of learning processes occurring in the program, and the expected outcomes from the learning processes. As well, it provides summaries of the overall qualities and expectations of the graduating student, career potential, and objectives of the program.

The curriculum redesign process has provided an excellent opportunity to revisit this program's curriculum in the wider context of the university community. In this paper, we share our experiences in the development and analysis of the manufacturing engineering explicit syllabus as well as our thoughts on the future direction of manufacturing at the University of Calgary. In particular, we focus on the development of a

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clear set of design courses (i.e. a 'design stream') in response to the university's strategic direction and recent changes in accreditation requirements.

MANUFACTURING ENGINEERING AT THE UNIVERSITY OF CALGARY

Post-secondary education in Canada including universities, colleges and technical schools is provincial jurisdiction. Therefore, the provincial governments fund degree programs based mainly on their own needs. The economy in the Province of Alberta has been resource-based. The oil and gas industry historically brought in most of the revenues, while the manufacturing sector in the province was dominated by many very small manufacturing shops that supply minor equipment or facilities to the resource industry.

In recent years however, Alberta's economic landscape has changed considerably. For example, from 1985 to 1999 while Alberta's GDP almost doubled (from $61.3 billion to $115.4 billion respectively), the energy sector's contribution to the GDP reduced by nearly half (from 37% to 21% respectively) while the manufacturing sector's contribution nearly doubled (from 6% to 11% respectively) [6]. For example, we have some major manufacturing enterprises such as Nortel Networks, Sanmina and Selectron in electronics and wireless equipment manufacturing, SMED and Dynamics Furniture in wood products and furniture manufacturing, and so on. Clearly, the importance of manufacturing cannot be ignored as Alberta enters the twenty-first century.

To continue to remain competitive in what is becoming increasingly a global market however, local manufacturers find themselves involved in a strategic transformation from traditional manufacturing shops to modern manufacturing enterprises. As a result, these companies require a new type of engineering professional: highly qualified manufacturing engineers who are not only well-versed in traditional manufacturing technology, but are also capable of keeping pace with this rapidly advancing field.

The development of the manufacturing engineering curriculum was carried out with both the present needs then and the anticipation of the future needs and evolution of manufacturing industry in Alberta. When the notion of a manufacturing engineering program at the University of Calgary was first conceived, Alberta had a few thousand very small manufacturing firms, most of whom employed fewer than 100 individuals. As a result, the needs of these companies for manufacturing engineers were quite different from those major corporations such as General Motors (GM). In addition, we had to bear in mind that the situation of relatively small manufacturing firms would not be changed significantly in the short term and that the impact of the communication and other technologies would be important to these firms to compete beyond the traditional provincial boundaries.

The initial courses offered in the early 1980s were CAD/CAM and Robotics which were basically technological courses reflecting then the state-of-the-art technologies in the local manufacturing industry. These courses were offered to mechanical engineering students who would want to learn more manufacturing technologies. The experiences were very positive for both local manufacturing companies and students.

With the advent of advanced manufacturing technologies, and especially with an increased interest at a number of local companies in exploring CAD/CAM, robotics and MRP systems, the department (with the support from the Industrial Advisory Council) proposed to establish the Computer Integrate Manufacturing (CIM) Minor program in 1989. The minor program consisted of the following technical electives for mechanical engineering students:

- ENMF 401 Computer-Aided Design and Graphics
- ENMF 415 Integrated Manufacturing Systems I
- ENMF 505 Robotics
- ENMF 509 Integrated Manufacturing Systems II
- ENMF 515 Computer-Based Control for Manufacturing

The objective then was to provide mechanical engineering students with an opportunity to specialize in manufacturing engineering with an emphasis in computer integrated manufacturing technologies. The program was very successful in terms of manufacturing employers' satisfaction and student subscription of the program.

As the Minor Program in Computer-Integrated Manufacturing was progressing, the structure of the provincial economy was evolving from mainly resource-based economy to a more diversified one with a significant portion of the revenue from the manufacturing sector. It was clear that the long-term strategy for the economic diversification must have a focus and the importance of the manufacturing sector is obvious.

To respond to the growing needs of Alberta manufacturing industry, with the support from the leadership of manufacturing industry in Alberta and the University as well as the Government, the Department of Mechanical and Manufacturing Engineering started a full degree program, i.e., B.Sc. in Manufacturing Engineering in 1995.

KEY FACTORS INFLUENCING CURRICULUM DESIGN

The manufacturing engineering curriculum was designed to provide students with knowledge and expertise that are critical for manufacturing competitiveness as defined by the US Council on

Competitiveness, the Canadian Manufacturing Association, and the Society of Manufacturing Engineers (SME). To meet the needs of industry, the diverse nature of manufacturing in Alberta had to be taken into account. For example, manufacturing in Alberta ranges from food processing to oil and gas equipment manufacturing, and is carried out by companies that range from a few employees to thousands of skilled workers. As a result, the manufacturing engineering curriculum had to be designed on a firm foundation of manufacturing fundamentals, but with the flexibility to allow students to pursue special topics that address the needs of local manufacturers (e.g. project management, computer-based control, artificial intelligence).

Two of the key factors that influenced initial curriculum design are embodied in the words 'manufacturing' and 'engineering'. First, close attention had to be paid to the selection of core courses and technical electives to ensure that our graduates are well prepared for the manufacturing discipline. Secondly, the entire program had to be designed to ensure that our graduates satisfy the academic requirements for registration as professional engineers in Canada.

As noted previously, the B.Sc. in Manufacturing Engineering curriculum was not developed in isolation, but involved input from industry as well as consultation with national and international manufacturing engineering organizations. In particular, we felt that our curriculum should reflect the fundamentals of manufacturing engineering as defined by the Society of Manufacturing Engineers (SME) and the Manufacturing Engineering Certification Institute (MECI). As a result, the manufacturing engineering program focuses on all of the key aspects identified by SME/MECI [7];

- *mathematics*: calculus and differential equations, linear algebra, probability and statistics, and numerical methods;
- *physics and engineering science*: organic and inorganic chemistry, units of measure, light and sound, electricity and electronics, statics and dynamics, strength of materials, thermodynamics and heat transfer, and fluid power;
- *materials*: material properties, metals, plastics, composites, and ceramics;
- *product design*: engineering drawing and communication, dimensioning and tolerancing, computer-aided design, product design tools, and team-based design project experience;
- *manufacturing processes*: cutting tool technology, machining, metal forming, sheet metal working, powdered metals, casting, welding, finishing, plastics, composites and ceramic processes, and hands-on 'practicum' experience;
- *production systems*: traditional production planning and control, lean production, integrated manufacturing systems, enterprise resource planning systems, supply chain management, and modeling and simulation of manufacturing systems;
- *automated systems and control*: computers and automation theory and practice of computer numerically controlled machines, robotics, and programmable logic controllers;
- *manufacturing management*: human behavior in organizations, leadership, team-building, communication, project management, engineering economics, professional duties and responsibilities, ethics and the engineering profession, public and worker safety and health, management of technology, and human resource management;
- *quality*: sampling, statistical process control, process capabilities analysis, process improvement tools and strategies, product function analysis, quality economics, quality management philosophies, and quality standards.

In addition to the need for a strong foundation in the fundamentals of manufacturing engineering, our program must also meet the requirements of the Canadian Engineering Accreditation Board (CEAB) to ensure that our graduates have the academic background necessary to register as professional engineers in Canada. In order to ensure that an undergraduate engineering program meets or exceeds educational standards acceptable for professional registration in Canada, the CEAB conducts a qualitative and quantitative analysis of the program's curriculum content. This analysis is performed by a visiting team consisting of registered professional engineers (from industry and academia) who report their findings to the CEAB; the CEAB then makes an accreditation decision.

When assessing an engineering program, the CEAB must ensure that the program's graduates will be competent in engineering science and also have an appreciation and understanding of the effect of engineering on society. As a result, engineering programs must contain adequate mathematics, science and engineering content, and also show that students develop communication skills and an understanding of the environmental, cultural, economic and social impacts of engineering on society and of the concept of sustainable development [2]. The program visitors look at the curriculum, course materials, and facilities in detail and conduct interviews with teaching faculty, administrators, students and support staff to judge how well these areas are covered. In addition to this qualitative assessment, the program visitors perform a quantitative assessment of the curriculum to determine if the program includes at least a minimum of the following curriculum components: mathematics, basic sciences, engineering science, engineering design, and non-technical subjects that complement the technical aspects of the curriculum [2]. The measure that is used by the CEAB for this purpose, the Accreditation Unit, is directly proportional to the actual contact time for an activity (i.e. lecture, tutorial and laboratory hours).

Like all new engineering programs, the B.Sc. in Manufacturing Engineering program was first assessed during the year the program's first students graduated (1997). The program was fully accredited at this time, then after the 2000 review of the Department's Mechanical and Manufacturing Engineering programs, our program was accredited for the maximum length possible (6 years) by the CEAB.

The requirements of the manufacturing discipline (SME/MECI) and the Canadian Engineering profession (CCPE/CEAB) provided the key influencing factors for initial curriculum design. In the remainder of this paper, we describe the resulting curriculum then focus on how the University of Calgary's broad strategic curriculum design initiative has further influenced curriculum design.

THE MANUFACTURING ENGINEERING CURRICULUM

Like all engineering programs at the University of Calgary, the B.Sc. in Manufacturing Engineering is a four-year program with an optional internship route, which adds an additional year to the regular four-year academic program. The internship year is taken after the third year and involves a minimum of twelve and a maximum of sixteen consecutive months of supervised work experience in industry. For more information on this program, the paper by Dorjee *et al.* [4] can be consulted.

The manufacturing engineering curriculum is shown in Fig. 1. The first year is common to all programs and can be though of as a foundation year that is used to help students develop the core competencies required for success in further engineering studies. The second year is common to the Mechanical and Manufacturing Engineering programs and also shares many courses with the other engineering disciplines. This year can also be thought of as a foundation year that focuses heavily on the engineering science required to support later discipline-specific courses in senior years.

The University of Calgary curriculum redesign process will be described in more detail in the next section. However, at this point we should note that the first step in this process involves the identification of 'course clusters': for example, natural clusters based on subject matter or the role that they fulfill in the program, or clusters based on educational objectives. The manufacturing engineering curriculum was divided into five course clusters based on subject matter. Although a course cluster was not identified based on educational objectives, the design stream discussed later can be thought of in this fashion.

FIRST YEAR	1	AMAT 217 - CALCULUS FOR ENGINEERS AND SCIENTISTS
	2	AMAT 219 - MULTIVARIABLE CALCULUS FOR ENGINEERS
	3	CHEM 209 - GENERAL CHEMISTRY FOR ENGINEERS
	4	ENGG 201 - BEHAVIOUR OF LIQUIDS, GASES AND SOLIDS
	5	ENGG 205 - STATICS
	6	ENGG 233 - COMPUTING FOR ENGINEERS I
	7	ENGG 215 - ENGINEERING DESIGN, PRACTICE AND COMMUNICATION
	8	ENGG 249 - DYNAMICS
	9	MATH 221 - LINEAR ALGEBRA FOR SCIENTISTS AND ENGINEERS
	10	PHYS 259 - ELECTRICITY AND MAGNATISM
	11	PHYS 269 - ACOUSTICS, OPTICS AND RADIATION
SECOND YEAR	12	AMAT 307 - DIFFERENTIAL EQUATIONS FOR ENGINEERING STUDENTS
	13	CHEM 357 - INDUSTRIAL ORGANIC CHEMISTRY FOR ENGINEERS
	14	ENGG 311 - ENGINEERING THERMODYNAMICS
	15	ENGG 313 - ENGINEERING DRAWING AND COMPUTER GRAPHICS
	16	ENGG 317 - MECHANICS OF SOLIDS
	17	ENGG 319 - PROBABILITY AND STATISTICS FOR ENGINEERS
	18	ENGG 325 - ELECTRIC CIRCUITS AND SYSTEMS
	19	ENGG 335 - COMPUTING FOR ENGINEERS II
	20	ENME 341 - FUNDAMENTALS OF FLUID MECHANICS
	21	ENGG 407 - NUMERICAL METHODS
	22	COMPLEMENTARY STUDIES COURSE

THIRD YEAR	ES	23	ENME 421 - MATERIALS I
		24	ENME 461 - MECHATRONICS
		25	ENME 473 - KINEMATICS AND DYNAMICS OF MACHINES
		26	ENMF 405 - MECHANICS OF MATERIALS
	MT	27	ENMF 401 - COMPUTER-AIDED DESIGN AND GRAPHICS
		28	ENMF 411 - QUALITY ASSURANCE
		29	ENMF 415 - INTEGRATED MANUFACTURING SYSTEMS I
		30	ENMF 417 - MANUFACTURING AND PRODUCTION PROCESSES
	MM	31	ENMF 407 - HUMAN BEHAVIOUR IN ORGANISATIONS
	CS	32	COMPLEMENTARY STUDIES COURSE
		33	COMPLEMENTARY STUDIES COURSE
FOURTH YEAR	ES	34	ENMF 521 - MANUFACTURING PRACTICUM
	MT	35	ENMF 501 - MODELLING AND SIMULATION OF MANUFACTURING SYS.
		36	ENMF 509 - INTEGRATED MANUFACTURING SYSTEMS II
		37	ENMF 533 - ELEMENTS OF AUTOMATION
	TE	38	TECHNICAL ELECTIVE COURSE
		39	TECHNICAL ELECTIVE COURSE
	CS	40	ENGG 513 - THE ROLE AND RESPONSIBILITY OF THE P.ENG. IN SOCIETY
		41	COMPLEMENTARY STUDIES COURSE
		42	COMPLEMENTARY STUDIES COURSE
	DM	43	ENMF 512 - MANUFACTURING ENGINEERING DESIGN METHODOLOGY
		44	ENMF 512 - MANUFACTURING ENGINEERING DESIGN METHODOLOGY

ES = Engineering Science
MT = Advanced Manufacturing Technologies
MM = Manufacturing Management
IT = Information Technologies
CS = Complementary Studies and Liberal Arts
DM = Design Methodology
TE = Technical Elective Course (3 in ES, 5 in MT, 2 in MM, 3 in IT)

Fig. 1. The manufacturing engineering curriculum.

The curriculum consists of four major components: fundamentals of engineering sciences, advanced manufacturing technologies, manufacturing management, and information technologies. The program also covers human dimensions in terms of communication, team work and leadership skills. Although aspects of all of the components exist in every course in the curriculum to varying degrees, it is convenient to cluster the courses in terms of these components. As a result, we can think of the curriculum as being divided into five 'course clusters' as described in the following sub-sections: i.e., the four major components plus a complementary studies and liberal arts cluster. In the following sub-sections, we describe the senior years of the program (where students specialize in a given engineering discipline at the University of Calgary) in the context of these five course clusters; the specific courses in each cluster are identified in Fig. 1.

- *Fundamentals of engineering science:* The objective of this cluster of courses is to provide students with a fundamental understanding of mathematical tools, engineering sciences, and basic sciences and technologies.
- *Advanced manufacturing technologies:* The objective of this cluster of courses is to provide students with solid grounding in current advanced manufacturing practices in areas such as, product engineering (e.g., CAD, reliability/maintainability, quality, continuous improvement), manufacturing processes (e.g., lean manufacturing, system integration, quality, JIT, tooling), manufacturing systems (e.g., automation, modelling/simulation, safety, integration), and physical controls of machinery (control systems, computer control, electronics, sensors/actuators).
- *Manufacturing management:* The objective of this cluster of courses is to provide students with a strong foundation in the basic management skills required of practicing manufacturing engineers such as business skills (e.g., cash flow, return on investment, engineering economics, operation of the manufacturing enterprise, understanding of entrepreneurship, customer focus, and life cycle costing), project management (planning, monitoring, time management, risk analysis, economic and cost factors, supply chain management), and human factors (e.g., organizations, negotiation, communication, as well as team-work and leadership skills).
- *Information technologies:* The objective of this cluster of courses is to allow students to pursue more advanced topics in the rapidly expanding Information Technologies (IT) area. These courses focus on how advanced computing and networking technology can be applied to manufacturing engineering design and operations problems.
- *Complementary studies and liberal arts:* The objective of this cluster of courses is to expose Manufacturing Engineering students to complementary studies as well as increase their contact with the Liberal Arts.

Engineering design

The core fourth-year course, Manufacturing Engineering Design Methodology and Application (ENMF 512) was intentionally not listed among the course clusters since it is intended to integrate a large portion of the concepts learned in the manufacturing program. As a result, this capstone course can be thought of as spanning all four course clusters.

Earlier aspects of the program focus on design and behavior of simple components as part of solving well-defined problems. The capstone design experience differs in that it is up to the design team to negotiate the scope of the project, manage all of the appropriate resources, and (most importantly) decide which design tools should be used along with how, when, and why. While specific courses are identified specifically as design courses, it can be seen that every course in the program can play a role in preparing the designer.

In a recent study by the Society of Manufacturing Engineers Education Foundation [8], representatives from various sectors of the manufacturing industry agreed that one of the key competency gaps of manufacturing engineering graduates is in the area of problem solving (e.g. problem identification, problem solution implementation, managing ambiguity, trade-off, looking for root causes, ability to prioritize). Our experience has been that this competency is well addressed with this full-year project approach to engineering design. This provides students with the opportunity to apply their technical skills, hone their oral and written communication skills, as well as practice their project management techniques and their abilities to interpret and assess a 'real-world' problem. For more information on this approach to engineering design education, the papers by Brusse-Gendre *et al.* and Caswell *et al.* can be consulted [1, 3].

CURRICULUM REFORM AT THE UNIVERSITY OF CALGARY

As noted previously, the University of Calgary embarked on its series of campus-wide program-level curriculum redesign projects shortly after the introduction of the B.Sc. in Manufacturing Engineering. In order to provide a framework for curriculum redesign, seven key features were identified that should be a part of all undergraduate programs at the University of Calgary [10]:

1. A clearly identifiable field of study.
2. A defined interdisciplinary component.
3. An international component.
4. An experiential learning component relevant to the program objectives.

5. Provision for broad and extended faculty-student interaction at the program level.
6. Integration of research.
7. An explicit program syllabus, which sets out in advance the knowledge and skills to be acquired in a program of study.

Each feature listed above will be discussed in more detail below; at this point though, more should be said about the last feature. One of the main deliverables at the end of the curriculum redesign process is an 'explicit program syllabus' that, like the initial explicit syllabus described previously, describes the program in detail. The main difference here (other than the obvious difference of describing the redesigned curriculum) is the document's intended audience. Rather than being used solely by faculty to analyse the curriculum, the explicit program syllabus is intended to be used by potential students and students in the program to describe where they are going and how they can get there. For example, the manufacturing engineering explicit program syllabus should include a jargon-free description of the manufacturing discipline (i.e. a 'clearly identifiable field of study') as well as the types of learning processes that occur in the program to help the student reach this 'destination'.

In the wider context of the University of Calgary, the student's final destination is not only defined in the relatively narrow terms of his or her field of study or discipline, but also in the broader terms of what one may think of as a 'university education'. These broader characteristics of University of Calgary students have been identified by the University's curriculum redesign team as a 'graduating student profile' and a set of 'core competencies' [10] as shown in Fig. 2. To reach this final destination, the remaining key features listed above (i.e. features 2–7) play a central role.

In the remainder of this paper we look at the manufacturing engineering program at the University of Calgary in the context of this curriculum redesign initiative. This process involved first describing the existing curriculum, then analysing the learning processes and expected outcomes in terms of the features and desired outcomes described in this section.

ANALYZING THE CURRICULUM

Curriculum design and redesign has been an ongoing process in the Department of Mechanical and Manufacturing Engineering since the mid-1980s that has involved most of the department's faculty, as well as the Manufacturing Engineering Industrial Advisory Committee composed of manufacturing industry, government, and senior university representatives. As a result, the general concept of curriculum redesign was not new to the department; instead, the university initiative provided us with an excellent opportunity to revisit this program in a broader context as discussed above. In the remainder of this section we will focus on these broader issues by looking at the first six of the University's key curriculum features. Based on this analysis, we then present our suggestions for improving the curriculum in the following section.

Clearly identifiable field of study

The idea of a 'clearly identifiable field of study' is to clearly answer the question 'What is a manufacturing engineer?' in manner that is useful to prospective students. Eventually, this definition will be used in the program's 'explicit syllabus' to help junior students to understand the profession and to make an informed decision at the end of their first year when choosing a discipline.

Graduating Student Profile

Graduates of the University of Calgary are intellectually powerful. They Can:

- Pose questions which approach the frontiers of knowledge.
- Solve the academic, professional, and ethical problems they face.
- Relate theory and practice.
- Establish and realize goals, working alone and with others.
- Communicate meaning in competent and effective ways.
- Engage meaningfully with those from other cultural and linguistic communities
- Understand the world from a variety of perspectives.

Core Competencies

Students should be competent at:

- Critical and creative thinking.
- Analysis of problems.
- Effective oral and written communication.
- Gathering and organizing information.
- Logical calculation.
- Abstract reasoning and its application.
- Insight and intuition in generating knowledge.
- Interpretive and assessment skills.

Fig. 2. University of Calgary curriculum redesign desired outcomes.

The pervasiveness of manufacturing in everyday life and the central role that manufacturing plays in the world economy leads to a common understanding of the basic nature of the manufacturing engineering disciplines. This common understanding however may mask the richness and diversity of this field of study. In particular, new sub-disciplines such as Biomedical Engineering and Mechatronics as well as technological advances in engineering and science research are constantly redefining what a manufacturing engineer is. For example, rather than the simple definition of manufacturing as 'a process of transforming materials from one form to another in a continuum of raw materials to finished products' [5], we propose a broader view of manufacturing to inform potential students of the true nature of this discipline.

Manufacturing is the engine that drives the economies of modern industrial nations—manufacturing engineers ensure that this engine runs smoothly and efficiently. The training of manufacturing engineers takes into account the complex, trans-disciplinary nature of this domain, and is directly aimed at the importance of the effective integration of people, equipment, and information that is the hallmark of world-class manufacturing.

This is a very broad definition of the manufacturing discipline allows one to see the manufacturing engineer as part of a 'bigger-picture'. Although technology plays an important role in modern manufacturing (e.g. automation, information technology) the focus here is integration in a very broad sense (i.e. the role of the manufacturing engineer is to be able to effectively integrate all aspects of the manufacturing enterprise—equipment, information, but most importantly, people).

Defined interdisciplinary component

What we may consider strictly as interdisciplinary in engineering may not be perceived as such in the wider university community. For example, the first two to three years of every engineering program involves courses from all engineering disciplines (e.g. chemical, electrical, mechanical, etc.) and the sciences (e.g. chemistry, math, physics).

By its very nature, engineering is interdisciplinary; this is particularly the case in the manufacturing domain. For example, when one considers Dowd's definition of the discipline noted previously [5], nature dictates that the basic types of transformation are inextricably linked to chemistry, physics and biology. As a result, scientists and engineers from practically all disciplines may find themselves involved in manufacturing. For example, Dowd notes that 75% of all engineering graduates (in the US) were employed by manufacturing companies in 1998.

As noted previously though, the jump from one engineering discipline to another may not be perceived to be broad enough 'interdisciplinary' studies to some members of the university community. In manufacturing, the obvious link to non-engineering or science disciplines is in the area of management; both the human aspects (i.e. communication, team work and leadership skills) as well as the more 'scientific' operations research aspects of the management discipline are present in the syllabus.

International component

This is somewhat problematic and is dependent upon how 'internationalisation' is defined. Clearly, students are constantly exposed to concepts from around the world in the engineering curriculum as well as to academic staff, a graduate student population, and cohorts from a variety of cultures. However, this can be just as easily stated for any program simply because of the international scope of academic pursuits.

Direct exposure to other cultures, languages, etc. is a different matter however. Although this would be immensely beneficial to our students (e.g. direct exposure to Japanese or European manufacturing practice), the cost and logistics involved in making this a core aspect of the manufacturing program are prohibitive. The internship program however, has provided our students with many opportunities in this area (please see Dorjee *et al.* [4]).

Experiential learning component

In the manufacturing engineering program experiential learning through design and problem solving are critically important components of the program. Students receive a wide variety of design experiences including the design of components, products, processes, systems and facilities. Furthermore, they receive strong exposure to material on the societal, environmental, and business context within which design must operate, as well as material on how advanced computational tools can be used to support design activities.

Faculty-student interaction at the program level

The fourth-year capstone design approach requires that the manufacturing engineering faculty step out of their traditional lecturing-mode of course delivery. For this course students work in small groups on unique projects and the role of the academic is shifted to becoming that of the coach or the consultant while the student takes 'centre-stage' (please see Caswell *et al.* [3]).

Although there are many other opportunities for close faculty–student interaction in the manufacturing program (e.g. special topics courses, tutorials, laboratories, professional societies and field trips), this aspect of the manufacturing engineering program addresses this curriculum feature most directly.

Integration of research

Although faculty members' current research may be introduced at any point in the program, it is most typically in the senior years of study where this is most appropriate. In the Department of Mechanical and Manufacturing Engineering, faculty members are involved in a wide range of manufacturing research that spans the majority of the topic areas in the curriculum. As a result, it is not surprising that experience from this research feeds into the manufacturing courses whether by design or in a more impromptu fashion.

The author's experience, however, has shown that it is important to point out the 'hot' research areas to students, as often students do not have a sense of the quick pace at which manufacturing knowledge advances. It is easy for students to develop a static view of their discipline and not realise the importance of life-long learning to keep apace with advances in their field. Clearly, one does not have to look too far into the past to see how a complacent attitude in the manufacturing industry resulted in a drastic reduction in North American competitiveness [11].

CURRICULUM REFORM IN MANUFACTURING ENGINEERING

Based on our analysis of the existing curriculum, we identified one main drawback: many of the courses in the program may appear to be compartmentalised and disconnected. As a result, some students tend to view them as hurdles that must be negotiated then forgotten. To address this problem, a main aspect of our curriculum redesign initiative has been a focus on a common design stream as illustrated in Fig. 3. This figure summarises the key players and forces that are currently impacting manufacturing curriculum design as well as the integrative role that design can play in the overall curriculum.

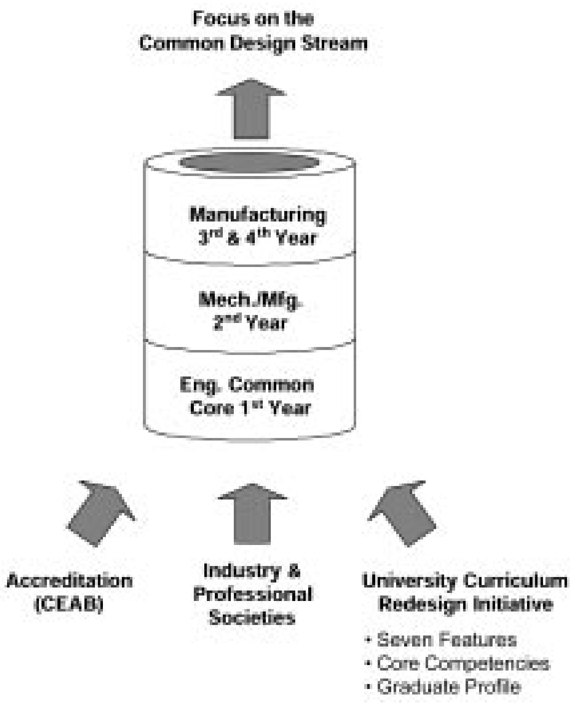

Fig. 3. Factors influencing curriculum design.

A main aspect of the B.Sc. in the Manufacturing Engineering curriculum has been a focus on a common design stream that fosters the creativity of our students and exposes them to innovative engineering practice. As noted by the Canadian Council of Professional Engineers (CCPE), 'engineering design integrates mathematics, basic sciences, engineering science and complementary studies in developing elements, systems and processes to meet specific needs' [2]. Our experience with the curriculum redesign process has reinforced the importance of engineering design in the curriculum and its ability to integrate various aspects of the curriculum through experiential learning, faculty-student interaction, integration of research, and in some cases, international experience. The notion of a common design stream follows from our success with the senior-year capstone design course, and extends this concept to each year of the program as is illustrated in Fig. 3.

Extending this idea to the entire program, our proposal for curriculum redesign is to have students involved in design during each semester of each year of the program as shown in Fig. 4. The idea is to integrate fundamental subject matter to solve complex problems and help students to understand the connection between the concepts they learn in courses and the practice of manufacturing engineering.

To implement this change, we foresee very minor changes in the senior years of the program: in third year, two existing design courses ('Computer Aided Design and Graphics' and 'Manufacturing and Production Processes') will be scheduled in the Fall and Winter terms respectively, while in the fourth year no changes are required. In the third year, 'Computer-aided Design and Graphics' (ENMF 401) introduces CAD/CAE tools for design and analysis (an optional advanced course in this area, 'Finite Element Method' (ENME 547), is also available). 'Manufacturing and Production Processes' (ENMF 417) explains different manufacturing processes and design considerations for manufacturing. In the fourth-year, small teams (typically four students) of senior mechanical engineering and manufacturing engineering undergraduate students complete approximately thirty design projects. Some of these projects are also entered in national and international competitions such as the Society of Automotive Engineers' Mini-Baha and Formula 1 competitions.

As shown in Fig. 4, more substantial changes are required in the first and second years. For example, the Department and Faculty are currently looking at replacing two junior design courses ('Engineering Design Practice and Communication' and 'Engineering Drawing and Computer Graphics') with four design courses: two 'problem-solving and communication' courses in the first

Term & Yr	Existing	Content	Proposed	Content*
F 1 or W 1	ENGG 215	Basic design methodology; basic graphic and written communication; intro to engineering disciplines	*ENGG 251*	*Problem-solving and communication*
W 1			*ENGG 253*	*Problem-solving and communication*
F 2	ENGG 313	Projection theory; multiview drawing; dimensioning; descriptive geometry; pictoral sketching; manufacturing processes; 2D & 3D CAD	*ENMF 3xx*	*Product realization process - specification/verification; manufacturing processes; engineering drawing; tolerances*
W 2			*ENMF 3yy*	*Product realization process - geometric dimensioning; manufacturing processes; design for assembly*
F 3	ENMF 417 ENMF 401	Intro to manufacturing processes Engineering drawing principles and standards; wire frame & solid modelling; databases; CAD; automatic part programming	ENMF 401	Engineering drawing principles and standards; wire frame & solid modelling; databases; CAD; automatic part programming
W 3			ENMF 417	Intro to manufacturing processes; good manufacturing practices; design for manufacture
F 4	ENMF 512	Basic methodology; major project	ENMF 512	Basic methodology; major project
W 4	ENMF 512	Basic methodology; major project	ENMF 512	Basic methodology; major project

*New courses are shown in *italics*

Fig. 4. Proposed design stream curriculum.

year and two courses on the product realisation process in the second year.

The first-year change has already been made. Starting the 2002/2003 academic year, our first-year students are introduced to fundamental engineering design principles and engineering communication techniques in 'Design and Communications I and II' (ENGG 251/253). These courses serve as the road maps for the junior students to understand the relations among different components in the curriculum.

As part of this initiative, a dedicated design center was established this year in the Faculty's new Information and Communication Technologies (ICT) building in order to further enhance our students' design experience. The student design laboratories have a space of 400 m2 (3600 ft2) that includes 38 student workstations (each equipped with a computer with audio/visual capabilities, an extensive mechanical/electrical tool chest for prototyping and drawing boards), a dedicated workshop for larger prototyping equipment (e.g. CNC lathe/mill, vertical band saw, welding), and extensive multimedia facilities.

Our first experience with this approach to first-year design (the 2002/2004 academic year) was very positive. Students worked in small groups all year on common-theme projects; in this case, the theme was the Olympic Oval [9] and projects included the design of speed skating crash pads and a speed skating robot.

CONCLUSIONS

In this paper we have provided an overview of the development of the manufacturing engineering program at the University of Calgary. Curriculum design in manufacturing has been an ongoing process since the program's inception, and has been influenced by various factors such as the introduction of new minor programs, the availability of new learning tools, and engineering accreditation requirements.

In summary, when analysing the types of learning processes occurring in the manufacturing program, we found that all aspects of the program address the seven features. In other words, many of our courses have an interdisciplinary component, an experiential learning component, integrate research, and have a considerable amount of faculty–student interaction. For example, the 'seven features' are clearly illustrated in the program's design courses, for example, design is interdisciplinary by nature, demands experiential learning, must by leading edge, and involves close student/faculty interaction. One area however, where we are lacking is that more focus is required on internationalisation. Currently we are looking into potential exchange programs with foreign universities to address this issue.

Similarly, as we looked at the objectives and expected outcomes of the learning processes in our program we felt that many of the 'core competencies' listed in Fig. 2 are intrinsic outcomes of engineering design and problem solving. An example of this can be seen in the fourth-year design course: this course provides students with an open-ended design problem at the beginning of the fourth year that they have to solve over the course of the year. As a result, this course demands critical and creative thinking, analysis of problems, and gathering and organising information.

Based on our experience with and our analysis of the existing curriculum, we feel that the key to achieving the desired outcomes of curriculum redesign as summarised in Fig. 1 lies in the integrative role that engineering design plays in the curriculum. Currently, we are focusing on the implementation of this idea in the curriculum of both the mechanical and manufacturing engineering undergraduate programs.

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