T6011 Department Level Curriculum Reform

Two innovations: five-year program in Engineering and Management and the MPS program

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Two unique curricular approaches have been taken at McMaster University.
In the Five-year *Engineering and Management* program students graduate with a fully-accredited degree in engineering plus the core courses of Bachelor of Commerce degree (micro and macro economics, finance, accounting, marketing, policy, organizational behavior, operations research); this is more than the first year of an MBA, plus unique Engineering and Management courses developed with industry on communication, people skills and project work for an external client that requires both commerce and engineering expertise. Although the program requires five years, the trick was to provide the required 42 credit hours of MBA material plus 6 units of commerce electives but only require one additional year of 38 credit. This was achieved by astutely providing credit within both programs and by spreading the courses carefully through the five year program. The first graduates were in 1975. The response by alumni and recruiters has been extremely positive. We have restricted enrolment in the program.

The MPS program was created in response to the need to improve our students skill in problem solving. We did an extensive five year research program to determine what we might do. We discovered that additional skills besides problem solving were needed (including time and stress management, interpersonal skills, conflict management, learning skills, goal setting, creativity, analysis, critical thinking, self awareness of uniqueness, lifelong learning, self assessment and so on). We found that workshops were the most effective vehicle to develop such skills. In the McMaster Problem Solving (MPS) program about 120 hours of workshops were spread over four required courses in the four year program (one course in sophomore year, two in junior year and one in senior year). The program was implemented in 1982. Details are given of the MPS program and its effectiveness at http://www.chemeng.mcmaster.ca/innov1.htm and MPS.

A common concern of Departments is how to best prepare students for their careers. Sometimes this dilemma is expressed as “to what extent should we include the business and management issues in our program?” Don’t many engineering graduates take an MBA anyway? Another dilemma is “to what extent should we develop our students *process skills* in such areas as problem solving, team work, interpersonal skills, self assessment and lifelong learning. After all graduates of our program are good at problem solving because in a typical four-year engineering program they solve more than 3000 homework problems (1)”. Semiconductors, bio, pharmacy, product design, energy, environment, safety, green engineering - the list goes on about different specializations that we might include in our program. How do we handle this, and more importantly, how do we anticipate such trends because it takes about five years of development work and getting students through our program before we can produce graduates with these “specialty skills”?

We too at McMaster University have tried to address these issues. Our response has been to develop a unique five year dual degree program in Engineering and Commerce called the Engineering and Management program. Secondly, we implemented the McMaster Problem Solving program to develop process skills and skill in lifelong learning that hopefully obviates the need to have many specializations to meet the ever-changing demands.

In this paper we describe first the Engineering and Management program; then the MPS program.

1.What about dual-degree programs in five years? McMaster’s Engineering and Management Program

Here we consider the rationale, the challenges and opportunities, the Commerce core, efforts to integrate the engineering and business elements across the curriculum, integrating professionalism with academia via the Industrial Advisory Council, comparing the Engineering and Management graduate with a four-year engineering graduate plus one year of an MBA, and the response to the program. In Section 1.8 we describe how this five-year model has been extended to other areas at McMaster University.

1.1 Rationale

In the late 1960 our faculty realized that there was a need for engineers with the core ideas from Commerce that make up the first year of an MBA. The vision was for a five year program that blended of all the required courses for an accredited degree in Engineering with the core courses in a Bachelor of Commerce degree. Rather than calling this a combined degree in Engineering and Commerce, a new title Engineering and Management (B.Eng Mgt) was selected. The graduates of the program are fully accredited Engineers in each of the Engineering programs: Chemical, Computer, Electrical, Engineering Physics, Materials, Mechanical, Mechatronics and Software.

1.2 Challenges and opportunities

Such a program could not have been successful on our campus without the whole hearted cooperation between the Faculties of Commerce/Business and the Faculty of Engineering. We wanted the engineering students to take the commerce courses along with the commerce students and we wanted to program to be available to students in all of the engineering disciplines.

First, to prevent the commerce courses from being overloaded there were enrolment restrictions; the program was limited to 75 students.

Next, to fit the core Commerce into the one-year time, there had to be negotiations. The Bachelor of Commerce program has a required core of 42 credits. To achieve the integration with the required Engineering programs of each of the engineering disciplines without loss of parts of either the Commerce core or the full Engineering components, the Mathematics and Science courses are credited for both programs. Thus, 21 credits of Mathematics needed in the Commerce program are provided by the Mathematics taken in the Engineering program. In addition 12 credits out of the 18 credits of Humanities electives required by Engineering accreditation are allocated to Organizational Behavior, Economics and Commerce courses from the core of the Commerce program. The resulting integration maintains all the required components of both the Engineering and Commerce degrees.
Admission to the program is after the freshman year and by application.

Another challenge, once the program was approved, was time-tabling. The core Commerce courses had to be available to engineering students from all different branches of engineering. The Engineering and Management courses had to be available to students of all engineering disciplines.

The Director of the program was selected for 3 year term and alternated from being selected from the Faculty of Business and the Faculty of Engineering. The Director was expected to attend Faculty meetings in both faculties and to take a strong interest in both faculties.

1.3 The Commerce core

The core Commerce courses include 12 credits of economics (introduction, intermediate price theory, intermediate income and employment theory); 6 credits of organizational behavior (introduction and either industrial relations or personnel); 6 credits of marketing (introduction and market research); 6 credits of accounting (financial, cost and management accounting); 6 credits of finance (financial instruments and institutions; management finance); 6 credits of management science (production and operation, business policy) plus two electives.

All the courses are taken with students registered in the Commerce program. There are not separate courses for the engineers.

1.4 Integrating Engineering and Management courses

To integrate the two disciplines and to develop esprit de corps among the students in the five year program for all engineering disciplines we have a variety of Engineering and Management courses. These courses have evolved over the years. Because of my familiarity of the courses when I was director, these are the ones described here.

Two non-credit Engineering and Management seminars in years two and three. Activities included critiquing Tom Peters videotapes, fundamentals of communication, personal uniqueness, self performance analysis, law and career planning. The seminars could ask for no homework They had about 90% attendance and were extremely popular and useful in developing esprit de corps and providing skill development often missed in other formal programs.

Two one-credit, week-long Engineering and Management skill development workshops after years three and four. The first series of workshop focused on problem solving, creativity and decision making; the second workshop considered interpersonal skills, conflict resolution, networking, interacting with the media, dealing with difficult behaviors and creating mission and vision statements. The workshops were from 9am to 5pm for five days and were presented by Human Resource personnel from companies and from our faculty. They were typical of in-house workshops. They were conducted the first week after exams. The arrangement was that students would be hired by a company and paid to attend the workshops. In return the company could send to the workshop, free of charge, one employee for every student. This was very successful win-win situation.

Two Engineering and Management Communications courses. Students wrote reports on their summer work experience and how it relates to the career plans and the theory they have studied. The written reports are marked and discussed individually with the students by both faculty and professionals from the Industrial Advisory Council. Speeches are videotaped and reviewed privately.

Final year Engineering and Management project. Teams of 10 to 15 students from different engineering disciplines work on interdisciplinary projects from an industrial client that require project definition, market surveys, financial considerations, engineering calculations and project planning and scheduling. The results are presented orally to the client. Clients included Eldorado Resources (how best to satisfy our energy needs); Corundol Environmental (how to use current facilities to best respond to future trends); Joseph Brant Memorial Hospital (critique and recommendations for energy utilization); Wallace Barnes (increase production efficiency and market capacity for one of its product lines).

1.5 Integration of professionalism with academia via the Industrial Advisory Council

One of the major keys to success is the hard working industrial advisory council. The IAC are mid to senior level engineers who are managers from a cross-section of industries. Besides offering guidance and advice about the program, the Council members are vital to three and sometimes four educational components. First, each is a mentor to 15 students. They take an interest in the student's progress, provide insight about their organization and provide field trips. Each council member marks the student's written reports and personally goes over the reports with each student. Council members suggest projects for the projects course. Occasionally, they interview first year students applying for admission into the Management program. They are looking for leadership qualities.

The council usually meets several times a year to advise the Director and the Operating committee about the program.

1.6 Comparison between the Engineering and Management graduate and four-year engineering graduate plus one year of an MBA

The five advantages are:
1. The E&M graduate has taken 16 more credits of Commerce than one would take in the first year of an MBA.
2. The commerce and engineering courses are integrated throughout the program instead of being considered separately in sequence.
3. The interaction with the Industrial Advisory Council and the students and the mentor program helps the students understand how organizations function.
4. The E&M program provides a double and perhaps a triple emphasis on "communication skills": perhaps from within the engineering discipline, from within the commerce program and from within the E&M program.
5. The Commerce and Engineering courses are carefully planned so that there is no overlap. However, some engineers taking their first year of the MBA may be required to take mathematics courses where they have had "almost all of the math before."

1.7 Response to the Program

Based on the response from industry and the fact that most graduates receive a position by the time they graduate, this is a very successful program. Some companies come on campus just to recruit E&M students.

1.8 McMaster's other five-year programs

At McMaster we offer a five-year *Engineering and Society* program and a five-year Chemical Engineering and Bioengineering degree.

Like the Management program, the Society program is open to students in all engineering disciplines. The purpose of the Society program is to explore the human side of engineering and the complex interactions between technology and society. The program includes Engineering and Society focus electives plus integrating Engineering and Society courses that address the history, culture and social control of technology. http://www.eng.mcmaster.ca/engandsoc/
Within the Society program is the Engineering and International Studies program to help future engineers to better understand the complexities associated with global project management. The emphasis is on an understanding of and a sensitivity to the different cultural, political, religious

and historical backgrounds of potential collaborators, as well as additional technical training in areas that are particularly important in international settings, such as international project management and supply chain management.

Unlike the Management program, the five-year Chemical Engineering and Bioengineering degree is only open to students in Chemical Engineering. This program is a unique 5-yr program that combines the core, accredited Chemical engineering undergraduate curriculum with courses from the life sciences (biology, human anatomy and physiology, biochemistry of macromolecules, cellular and molecular biology) as well as integrating courses on bioreactors and bioseparations. http://chemeng.mcmaster.ca/programs.html

2. The McMaster Problem Solving Program

Consider first the rationale. Then we consider visualizing the curriculum, identifying the core fundamentals, the set of skills, the target behaviors of the process skills and the associated learning objectives, and how to develop the process skills; designing the workshops and the course sequences, and implementing and evaluating effectiveness.

2.1 Rationale

In the 1970s we realized two things: a) feedback from industry suggested that our graduates did not have skill in problem solving and b) the job market wanted some graduates in environmental engineering and some in semiconductors, in the former specialty we offered perhaps one or two courses but in the latter we offered no courses. This could be expressed as two generic questions: 1) how do we develop our student's abilities in the *process skills* (that some call soft, generic, higher order thinking or procedural skills) needed by professionals in their career? These might include such skills as problem solving, communication, team work, performance review, listening, time and stress management, lifelong learning and conflict resolution.
2) How can we offer a program that will equip graduates to work in the wide variety of industries where the basics of chemical engineering are needed: such as pulp and paper, polymers, semiconductors, environmental, pharmacy, foods, fertilizers, petrochemicals, refining, and tar sands.
The glib answer to both these questions is to develop our students skills in problem solving and in lifelong learning. If the graduates have confidence and skill in lifelong learning then we don't need to offer specialized courses beyond the fundamentals. No matter what the professional expectation is in their career they can learn and apply the new information if they know the fundamentals and can apply lifelong learning. Fortunately at that time McMaster Medical School had started its revolutionary program of small group, self-directed, self-assessed, interdependent problem-based learning. This was a unique and effective way to develop lifelong learning skills. Fortunately, we attended their workshops and learned much about their approach. However, this Medical School approach was challenging for us to implement because for the Medical School a) one admission criteria included performance in a PBL session that required skill in problem solving and team work (whereas students in most programs were admitted based on primarily on marks), b) students admitted to the medical school were usually graduates of

other undergraduate programs (and were therefore three to four years more mature than our engineering students), c) the whole program was PBL so that one faculty tutor could be assigned to a group of five students (whereas in engineering one faculty member would have a class of about 30 to 100 students) and d) most of the material was developed in the context of health sciences. Hence, attractive as this pedagogical approach might be, major modifications were needed to make it effective in our engineering classrooms.

2.2 Visualizing the curriculum

We realized that we couldn't convert our whole program to PBL; we hoped that we could have some senior level courses that could use PBL and we hoped that that exposure was sufficient to develop the required confidence and skill in lifelong learning. In previous courses we would focus on developing the process skills to make PBL work with autonomous, small groups of 5 such that 10 to 15 autonomous student groups would work as effectively as if they had a tutor present in the group. Self-assessment and self awareness thus became major skills to develop in addition to the problem solving and team skills. The steps to take included identifying the core fundamentals, learning how to develop the process skills, identifying the target behaviors of the process skills, designing the workshops and course sequences and implementing and evaluating the effectiveness.

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2.3 Identifying the core fundamentals

Whereas senior students tend to see Chemical Engineering as 2000 equations that they have to memorize, we wanted them to be soundly based in the seven core fundamentals: conservation of mass, species, momentum, energy and charge and fundamentals of phase equilibrium and chemical reaction equilibrium. We visualized, for example, the conservation of energy via a concept map illustrating the extension to thermodynamics, fluid mechanics, heat transfer and reactor design. Copies of this map can be obtained from the author at <woodsdr@mcmaster.ca>. Scrutiny of the courses we taught suggested that about 2/3 of each course content was prerequisite for subsequent courses and about 1/3 was interesting enrichment that was not required subsequently. The result was that we could free-up about 12 credit hours to focus on the process skills to build up to the use of PBL, and that the core fundamentals could be addressed through courses before the beginning of the senior year. This would leave the senior year open for "graduate level" electives through which students could elect to experience the research specialists of the faculty.

2.4 Identifying the set of skills

It might sound obvious that the skills a professional requires includes problem solving, creativity, decision making, team work, and interpersonal skills. But how might we break those down into a subset of skills. Where do listening skills fit in? Is it important to include translation skills to convert a set of words into a diagram or do our students possess that skill already? To identify the skill set (and perhaps how to and how not to teach them) we received funding for a four year project during which a faculty member became a student again, attended all the required courses with the students. He met weekly with a cohort of the students to discover how they were 'solving the ordinary homework problems", learning how well they could extract the fundamentals from their courses and create a diagram of the structure of the knowledge and how it interacted between the Chemistry, Physics, Mathematics and other courses they were taking. From this we could determine details about the skill set needed by the students. I became a student again in 1974 and followed the same cohort through the four year program. I "graduated" in 1978. Dr C.M. Crowe became a student again in 1975 and followed another cohort for one year to validate the results I had observed and to provide a check on the skill set.

2.5 Identifying that target behaviors of the process skills and the associated learning objectives

We need to base our program on the fundamentals of cognition and not on the intuitive approach published in "how to do it" books. Fortunately there is a rich set of *novice* versus *expert* research from which we can extract the target behaviors (2). From such targets we created observable, learning objectives with measurable criteria (3) for each of the skills and subskills.

2.6 Identifying how to develop the process skills

From the above-mentioned research project we met with the cohort of students as we followed them through the four year program. During those meetings we would try different options to help them improve their skill; we invited different experts to observe and suggest how we might develop the skills. We discovered that, for example subject knowledge (of lack thereof) often interfered extensively with the problem solving process. It was crucial to set up situations that would help us discern whether the fault lay with a lack of knowledge or lack of problem solving skill. From this we learned to adjust our program to provide workshop experience on subject-independent content. In addition, we sat in on about half a dozen industrial in-house workshops to develop these skills. Bandura (4) provided insight as to how change skills and attitude via his research on how to change phobias. He found that observing someone successfully handle the phobia was ineffective. He recommended that the whole process be divided into small sections that can be handled easily, that the person be given a chance to try the experience where there was an extremely high probability of success. The person would receive feedback and celebrate success. So the skill and confidence would be built layer by layer.
We planned early versions of some of the workshops and then tried them with volunteers and with professionals from the Instructional Development Centre as observers (5).

2.7 Designing the workshops and the course sequences

As Bandura has illustrated, workshops, that give participants a chance to try a skill and get prompt feedback, seem to be the most effective approach. Here are the steps we used.

Step 1. Define the skill base on research, not intuition. Publish target behaviors of successful persons performing the skill. Some examples are published:
http://www.chemeng.mcmaster.ca/innov1.htm and click on MPS and look for "target skills"

Step 2. Create learning objectives for the skill. Some examples are published:

http://www.chemeng.mcmaster.ca/innov1.htm and click on MPS and look for "objectives"

Step 3. Design the worksheets (feedback forms and forms of evidence that participants will use to show performance accomplishments)

Step 4. Work out the "timing sheets" for how you will manage the workshops.
An overall template for the workshops is as follows:

Define
Rationalize
Pretest
Objectives
Route ahead
Activity in subject-free context (eg puzzles, reasoning) with feedback
Reflections
Activity with feedback
Description of target behaviors
Activity with feedback
Reflections
Activity with feedback
Continue until the participants feel they can achieve the objectives
Objectives
Post Test
Discovery

The first activities are in subject-free contexts so that the participants can focus on **"building"** the skill. The next activities are to "**bridge"** the application to the subject domain. Here we ask for the same thinking behaviors but apply them in the context of Chemical Engineering. Finally, the participants are ask to "**extend"** the application of this behavior to their homework in any discipline or course and to their everyday life.
Reflection and self-assessment about the process and the skill acquisition are critical components to the process.

The formal required course sequence was:

48 hours of workshops in the sophomore year where the focus is on individual skill in problem solving, self assessment, time and stress management, personal uniqueness, creativity and analysis.
18 hours of synthesis and application of the previous skills in the first semester junior year.
24 hours of workshops in the second semester junior year where the focus is on knowledge structure, interpersonal skills and team work.
30 to 50 hours of workshops in the first semester senior year on solving ill-defined problems such as trouble shooting, systems thinking, chairperson skills, and learning engineering economics using PBL (6).

By the senior year, we were confident that our students possessed the required problem solving and team skills that they would be admitted into the Medical School PBL program via the simulated tutorial described above under Rationale. Hence, that was when we felt the students, working in tutorless groups, were ready for PBL.

2.8 Implementing and evaluating effectiveness.

The revised program was implemented in 1982. The PBL sessions worked so well in the senior year that the students requested that PBL also be used as part of a junior level course. Currently PBL is used in both a third and a senior course. Along the way we had to address issues different from the medical school because we were using autonomous or tutorless groups (7).

We published a major evaluation of the program (8) and specific articles related to problem solving (9); team work (10) and lifelong learning and PBL (11).

The MPS program continues, with some modifications; and attracts numerous visitors and sabbatical leave colleagues.

3. Summary

Two successful innovations were described: the five-year Engineering and Management program and the McMaster Problem Solving program. The rationale for these is given. Steps taken to design and implement these are listed. The overall evaluation of these approaches is given.

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