ENGINEERING EDUCATION IN CANADIAN UNIVERSITIES

A Report from

THE CANADIAN ACADEMY OF ENGINEERING

Prepared by a Committee
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September 1993

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SUMMARY

Canada's future prosperity and quality of life will depend in large measure on the incorporation of superior skill, intelligence and added value into its products and services while establishing a sound basis for a sustainable global environment. Professional engineers can play important roles in creating high-quality employment, establishing new enterprises, restructuring existing processes and developing new products and services. The basis for excellence in the engineering profession is excellence in the system of engineering education at undergraduate, graduate and career levels. It is imperative that this education system evolve effectively to meet these changing needs of Canadian society.

This report of the Canadian Academy of Engineering responds to a rising ferment in engineering education. Our engineering faculties are perceived to be scientifically strong by international standards but far from optimal in the contribution they could make to the initial and continuing education of engineers for effective practice of their profession in Canada. The report develops a new vision of engineering education and recommends a number of thrusts and directions to implement this vision . Some of the highlights are:

- Broader, less specialized, more integrated undergraduate programs with increased emphasis on design and social context.
- Increased interaction between engineering professors and practitioners in the profession.
- One-year professional masters programs.
- More formal development programs for Engineers-in-Training.
- More formal continuing education programs.
- Expanded cooperative research and development programs.
- Enhanced professional experience for engineering professors.

Significant changes will be needed in the cultures, policies and practices of universities, engineering faculties, industry, governments and the engineering profession if this report's vision of the role of engineers in assuring Canada's future welfare is to be achieved.

KEY RECOMMENDATIONS

- **Engineering Faculties** should:

  - ensure that undergraduate engineering programs are broadly based, inculcating those basic attributes that are of lasting value and applicability,

  - emphasize design, problem solving, the impact of engineering on society and the environment, communication, teamwork, leadership and practical experience,

  - provide one-year professional master's programs in engineering design, engineering management and engineering research and development,

  - emphasize research, development and design projects relevant to the solution of present and future problems and opportunities in Canadian society,

  - plan to recruit a majority of their professors after some years of effective engineering experience in industry or government,

  - encourage linkages with industry through cooperative and contract research, consultancies and sabbatical leave employment.

- **The Engineering Profession in Canada** should:

  - support a country-wide introduction of a more effective and longer (eg. four year) experience requirement for Engineers-in-Training prior to registration,

  - should introduce programs for recognizing participation in appropriate continuing education activities by professional engineers, with a view to making adequate participation an eventual requirement for continued registration.

- **Canadian Industry** should:

  - accept an ongoing responsibility to provide adequate practical experience opportunities for engineering students,

  - provide suitable development programs for Engineers-in-Training,

- provide opportunities, encouragement and support for continuing education programs for their professional engineers,

- provide well-qualified practising engineers to play a major role in the presentation of application-oriented undergraduate and professional master's programs,

- encourage linkages with universities through cooperative research and development, contracts and consultancies.

• **Universities** should:

  - ensure that their recruitment and advancement criteria for professors are sufficiently broad to include the special needs of engineering. These criteria should include appropriate recognition of teaching performance, research and development contributions, professional experience and accomplishments, and service to the community,

  - ensure that the rewards for good teaching are made as attractive as those for good research.

• **Governments** should:

  - make it a priority for public policy in Canada to ensure an adequate supply of qualified entrants to the engineering profession by providing appropriate targeted resources for engineering education,

  - encourage agencies such as NSERC, NRC, provincial research organizations and government departments to establish, expand and emphasize programs involving cooperative research and development by industry and universities,

  - provide support for continuing education for engineers through appropriate infrastructure.

• **The Canadian Academy of Engineering** should:

  - commit itself to a continuing role in promoting engineering education of appropriate content and quality, in cooperation with engineering faculties, universities, industry, professional associations, technical societies and governments,

  - focus efforts on informing the public on the role that the engineering profession plays in the welfare and infrastructure of the country, and on the important role of engineering as distinct from science or technology.

ENGINEERING EDUCATION IN CANADIAN UNIVERSITIES

1. INTRODUCTION

- This report sets forth principles and policies that the Canadian Academy of Engineering feels should guide the evolution of engineering education in Canada and makes recommendations for their implementation.

- This is a companion document to the report on "Engineering Research in Canadian Universities" [1] issued by the Academy in December, 1991. For convenience, some of the points raised in that report are integrated into this document.

1.1 The Role of the Academy in Engineering Education

- The Canadian Council of Professional Engineers (CCPE) and the National Council of Deans of Engineering and Applied Science (NCDEAS) have prepared a report "The Future of Engineering Education in Canada" [2]. The Academy strongly supports the initiatives of this report and is in agreement in principle with most of its recommendations. In particular, the recommendations of that report relating to pre-university education are welcomed. This Academy document is focused on education for engineering at undergraduate, graduate and lifelong professional levels. Many of the recommendations in the CCPE/NCDEAS report are revisited in this document with elaboration and extension.

- Those who have day to day responsibility for the administration of the profession and the engineering faculties are faced with formidable jurisdictional, bureaucratic, institutional and resource constraints .The Academy is deeply concerned about the future of engineering education and is committed to identifying and presenting needs for fundamental changes, however difficult these may be to implement. This document is therefore intended as a statement of the thrusts and directions that the Academy recommends as guidelines to universities, industry, governments and the engineering profession in the future evolution of engineering education.

- It is recognized that a number of the recommendations made in this report have already been implemented at some institutions and that others are in the process of being addressed by appropriate organizations. Conversely, some of the recommendations will, by their nature, take years to come to full fruition.

1.2 The Current Ferment in Engineering Education

- Major changes in engineering education occurred in the 1960's on the North American continent, in response to new scientific advances and, in large measure, to perceived needs of space and defence programs. Today, a similar wave of concern has emerged in response to a need for improved competitiveness of North American industry in the world marketplaces, and in response to a public desire for a future with sustainable development.

- In an earlier document [1], the Canadian Academy of Engineering expressed a view, held by many in industry and academe, that engineering faculties in Canadian universities have become overly concerned with their contributions to scientific knowledge and too little with the preparation of engineers for the effective practice of engineering in Canada. It is felt that, with appropriate changes in approach and emphasis, these faculties could make a much greater contribution to the wealth and well being of the country.

- The president of the Massachusetts Institute of Technology (MIT), Charles M. Vest, in a recent speech to the American Society for Engineering Education, has called for a major overhaul of engineering education, an overhaul that would emphasize design and production along with leadership and teamwork skills [3].

- The Department of Electrical and Computer Engineering at MIT plans to introduce a fifth-year Professional Master's Degree (M.Eng.) for a majority of its students and will make the Doctorate its first research-based degree [4].

- "A Study of Means to Improve the Quality of Research and Education in Mechanical Engineering at Canadian Universities" [5], prepared for Industry and Science Canada, emphasizes that "Engineering design and synthesis are at the very core of engineering and are essential to the international competitiveness of Canadian industry".

- In the USA, a 5-year project aimed at reforming engineering curricula is in progress. This "Synthesis Coalition" [6] includes such prestigious institutions as the University of California at Berkeley, Stanford University and Cornell.

- A recent report by the Québec Conseil des Universités, "Le développement du secteur de l'ingénierie" [7] recommends better definition of undergraduate objectives, increased attention to design, experience requirements for professors, professional master's programs and increased interaction of professors with the engineering profession.

- The report of the Canadian Committee on Women in Engineering, "More Than Just Numbers" [8], calls on engineering faculties to enhance the attractiveness of engineering for women by making their curricula more relevant to current social realities and future needs.

- Job creation is a priority for the years to come. Professional engineers with adequate education and experience can play an important role in establishing new enterprises, restructuring existing processes and developing new products and services.

- The implications of the North American Free Trade Agreement impose new demands on Canadian engineering education and present an incentive to provide education which will attract appropriate industry to locate in Canada.

- If an industry becomes insensitive to its market, it quickly loses its relevance and its customers. Similarly, universities and their engineering faculties are also vulnerable if they lose their sensitivity to their changing marketplace.

- In view of this growing ferment and in view of the present and future challenges facing Canada, it is imperative that there be a distinctly Canadian response to these concerns in engineering education.

1.3 What is Engineering?

- The design and delivery of engineering education must be based on a clear understanding of the role of the profession of engineering. The following points of definition are edited excerpts from the report "Engineering Research in Canadian Universities" [1]:

  > " Engineering is a profession concerned with the creation of new and improved systems, processes and products, to serve human needs as they are expressed by individuals, communities, governments and corporations."

  > " The central focus of engineering is design, an art entailing the exercise of ingenuity, imagination, knowledge, skill, discipline and judgement based on experience."

  > " The practice of professional engineering requires sensitivity to the physical potential of materials, to the logic of mathematical analysis, to the operational principles of processes and systems, to the constraints of human resources, physical resources and

economics, to the protection of the public, and to the social and environmental context for society, now and into the future. The professional engineer may be a specialist in a particular area of expertise, but must also be a generalist in order to practice that specialty in the real world."

- In the public mind, the term "engineering" is frequently lost between the more popular words "science" and "technology". This contributes to an inadequate understanding of the role that the profession of engineering plays in society.

RECOMMENDATION 1: The Canadian Academy of Engineering, together with other engineering organizations in Canada, should focus efforts on informing the public on the role that the engineering profession plays in the welfare of the country, and on the important distinctions between engineering and science or technology.

1.4 Goals of Engineering Education

- The primary goal of engineering education must derive from that of the profession of engineering, ie., to provide society with engineering services of high quality.

- The primary goal of engineering education must therefore be the formation and continued educational support of people who can provide these services and take responsibility for the continuing efficacy of these services.

- Research and development play a very important role in addressing this primary goal, both by generating new knowledge of value in providing engineering services and in providing an environment and community of intellectual enquiry within which the student develops the desired capabilities.

- There are several secondary goals which may also be included in the mandate of an engineering faculty:

  - The provision of a broad general tertiary education with technological content. This has proved to be advantageous to many who have subsequently entered other occupations or professions.

- The provision of effective contributions to the technological education of university students who are specializing in a variety of disciplines.

- The provision of education and policy advice to the public on engineering matters.

- While these other goals are important, this report focuses on the primary goal.

RECOMMENDATION 2: The Canadian Academy of Engineering should commit itself to an active and continuing role in promoting engineering education of appropriate content and quality, in cooperation with engineering faculties, universities, industry, professional associations, technical societies and governments.

RECOMMENDATION 3: Engineering faculties should adopt, as their primary goal, the educational formation of students in preparation for entry to the engineering profession.

2. UNDERGRADUATE ENGINEERING EDUCATION

- If engineering educators are to produce graduates well prepared for their professional careers, those educators must know and be responsive to their various and changing markets.

- Most graduates of undergraduate engineering programs follow one of three major career paths: (1) employment in a dominantly technical capacity, usually in industry or government, (2) employment dominantly in engineering management, usually after a few years of technical experience and (3) employment in a dominantly research and/or teaching capacity.

- At present, Canada's needs in numbers of engineers are mainly in the first two categories. The third category, though relatively smaller, is however of major national importance and the desired numbers will likely increase. All of these people can contribute significantly to innovations in industry and also play a major part in shaping the future graduates of our engineering faculties.

- Undergraduate students should not have to commit themselves to any one of the major career paths until they have had an opportunity to absorb the broad-based fundamentals of engineering.

- In Canada and elsewhere, students choose a particular discipline in engineering (civil, chemical, electrical, mechanical, etc.) either on entry or in an early year. This limited degree of differentiation has served the profession and the community well, but the appropriateness of this differentiation must be continually examined.

- Experience has shown that, when highly specialized undergraduate programs and options were provided, only a minority of graduates pursued employment in their chosen specialties. This observation demonstrates the desirability of a broadly based undergraduate program that includes those concepts which are fundamental to the discipline and also those which are basic to closely related disciplines.

- Rapid changes in technology can be expected to continue. Accordingly, building flexibility, breadth of outlook and ability for independent and continued learning should be primary objectives of the undergraduate program. Holistic system thinking has become increasingly important for engineers in today's world.

- Some have argued for the provision of two distinct and separate undergraduate streams: one directed at the practice of engineering and another with a highly scientific approach leading to a research career. Further, some have suggested that there should even be separate institutions for these streams based on the German models of the Technische FachHochschule and the Technical University. Such models are considered to be inappropriate for Canada with its widely distributed population and industry, its large number of relatively small engineering faculties and its limited opportunities for research employment.

- A more appropriate model for Canada is one in which each institution provides broadly based undergraduate engineering education with considered differentiation to reflect local conditions. Opportunity for further education and specialization in technical, management or scientific areas may then be provided at postgraduate level at some or all institutions depending on their capabilities, locations and emphases.

RECOMMENDATION 4: Engineering faculties should ensure that undergraduate engineering programs are broadly based and holistic in scope, including both those concepts which are fundamental to the discipline and those which are basic to closely related disciplines.

Specialization of programs at the undergraduate level should be avoided.

2.1 Curriculum Content

- The undergraduate program is of necessity of limited time duration. To make optimal use of this time, the focus of the program should be on an agreed set of basic attributes - knowledge, concepts, techniques, skills, habits and insights -that are believed to be of lasting value. Most of what has been valued in undergraduate education by past generations of engineers is that which has not become obsolete throughout long and effective careers. Examples are a basic physical understanding, a sensitivity to context and an ability and enthusiasm to learn.

- It is recognized that the lifetime of most technical information is short and is becoming increasingly shorter. Thus, the rationale for the inclusion of specific information content in the curriculum should primarily be its contribution to inculcating a concept, a habit, a mode of thinking, an insight, an ability to utilize and apply knowledge in a beneficial and responsible manner.

- Engineering curricula are devised by professors who are not primarily practitioners in the engineering profession. It is therefore important that professors establish and maintain adequate means for obtaining significant and continuing input from engineering practitioners who can reflect the present and future needs of the user in the marketplace.

- It is important that the curriculum structure provide for the inclusion of the societal and environmental context of engineering, with both its benefits and negative impacts. These concepts should be integrated into many courses and be associated with the development of an understanding of the role of engineering in creating the wealth essential to sustain the quality of life.

- It is essential the undergraduate curriculum include at least one opportunity to undertake a major design task. This task should be broadly based including such considerations as economy, safety, reliability, manufacturability, maintainability, environmental and social impact.

RECOMMENDATION 5: The curriculum content should be designed to inculcate those basic attributes - concepts, techniques, skills, habits and insights - that are believed to be of lasting value and applicability. Recognizing that the lifetime of most technical information is short, the rationale for the inclusion of specific information content in the curriculum should primarily be its contribution to development of these basic desired attributes.

RECOMMENDATION 6: Engineering faculties should establish and maintain adequate means for obtaining significant and continuing input from engineering practitioners who can reflect the needs of the marketplace.

RECOMMENDATION 7: The curriculum should provide for the inclusion of the societal and environmental context of engineering, with both its benefits and negative impacts.

RECOMMENDATION 8: The curriculum should include at least one opportunity to undertake a major design task. The selection of this major design should be such as to emphasize a holistic approach.

2.2 Educational Approach

- The engineering approach in which the curriculum is delivered is much more important than its detailed information content. The calendar description of a course should emphasize the educational objectives as well as the information content.

2.2.1 The Traditional Approach

- The traditional approach in engineering education has been dominantly a linear one, typified by mathematics and basic sciences in the early years, followed by engineering sciences, followed by a selection of optional specialty engineering subjects. The complementary, non-technical subjects in the arts, humanities and social sciences are usually distributed throughout the program. A major design project or thesis has normally been included in the final year.

- This traditional approach has several advantages:

  - it is familiar.

  - it seems logical and its linear approach is appealing.

  - it provides exposure of the students to mathematicians, and pure scientists.

- it permits engineering professors to concentrate on the subjects that they know best.

- the time allocated to specific curriculum content is readily quantifiable for purposes of accreditation.

- There are however several disadvantages:

  - subjects tend to be highly compartmentalized.

  - emphasis tends to be placed on the detailed information content of each individual subject. Frequently, the examination process promotes and rewards this emphasis.

  - the integration of these subjects, which is necessary for learning design, may readily be overlooked since it is not the responsibility of any particular course.

  - the assigned design components in individual subjects are often of a very specialized, narrow nature. This specialization frequently occurs even in the major design or thesis work.

  - members of the professorial staff tend to become specialized to the extent that they feel they can teach only a narrow range of subjects in the curriculum.

  - the value of professors as role models for the undergraduate students is diminished since they do not display the breadth and generality that should typify good engineering practice. Somehow, the student is expected to achieve an integration of all the subjects taken even though that integration may not be evident in contacts with the professors.

  - the complementary, non-technical part of the curriculum is frequently regarded both by students and staff as an externally-imposed requirement, probably good for the student's general education, but not relevant to the main thrust of the engineering program. In most instances, no one is made responsible for the integration of the non-technical content into engineering design.

  - the initial enthusiasm of entering students for engineering is diminished by the long wait before real engineering issues are introduced.

- The traditional approach to curriculum formation frequently leads to a tight compartmentalization of those individual subjects associated with particular departments or groups within departments. For example, policy and content in mathematics is frequently the province of the mathematics department. As a result, some of the mathematical concepts and techniques included may never be applied in later studies and may be of little lasting value to the graduate.

- The availability of computer software has had a major impact on the practice of engineering. Thus far, it has had all too little impact on the educational presentation of much of the fundamental material of the engineering curriculum due to a lack of appropriate educational software. At times, a contributing cause has been a shortage of computer facilities. However, a major reason for this lack is that the rewards to a professor for innovating, testing and producing such material are far less than for other activities.

- At present, the engineering curriculum is frequently steered by the research imperatives of the academic staff. All too often material is included in the curriculum because professors see a need for it in their specific research areas. They may exert pressure to include specialized elective subjects in the undergraduate curriculum so that prospective graduate students will be prepared for an earlier start on significant research. This tends to constrain the time available for the appropriate development of basic concepts and design philosophy.

2.2.2 An Applications-based Approach

- The approach to engineering education should be conditioned by some of the major factors affecting engineering practice today:
  - -the rapid growth of knowledge and information technology,
  - -the increasingly interdisciplinary nature of most technical ventures,
  - -the dominant role of small entrepreneurial companies in creating new high quality employment,
  - -the internationalization of the marketplace.

  To meet these challenges, students need to learn how to learn and their horizons need to be extended in breadth.

- Integration of the concepts and material of the curriculum should be made evident in each professor's presentation.

- Senior engineering professors who have a broad range of practising experience are the most competent persons to teach an integrated approach to the fundamental basic subjects in the curriculum.

- Design is the essence of engineering. It should therefore be a dominant theme of the whole undergraduate experience.

Engineering design should be broadly interpreted as a process of planning and action which meets the requirements of an engineering task with acceptable performance and quality. In this document, the term engineering design encompasses all of the aspects involved in the processes of problem formulation, problem solving, optimization, decision making and assessing the impact on the user society and on the environment. The term includes the design of manufacturing, production, marketing and maintenance processes, the design of an experimental program, the design of an operational structure for an enterprise. In some contexts, an appropriate alternate term for engineering design may be a "systems approach".

- Design exercises drawn from engineering experience can be integrated into the undergraduate engineering curriculum on a continuing basis, including appropriate examples in the introductory material on mathematics and the basic sciences.

- Early introduction of simple design examples can provide a means of introducing such fundamental engineering concepts as physical insight, engineering judgment and optimization. Such design exercises appeal to a broad range of learning styles and provide valuable motivation.

- Those who teach the introductory science concepts to engineers should be expert in the application of these concepts in meaningful examples. While these persons may occasionally be found in the departments of mathematics, physics and chemistry, they are predominantly in the faculties of engineering.

- The engineering science part of the curriculum currently places high emphasis on analytical concepts and techniques. Integrated with this should be a good introduction to the concepts of modelling, ie. the extraction from a real situation of an analytical model which has no more complexity than is justified by the particular needs of the exercise.

- The objective of elective subjects in the undergraduate curriculum should not be to produce specialists but rather to provide students with some of the skills that are useful in acquiring facility in a specialty when it is needed.

- An important skill is the ability to search out the specialized information. Design exercises should be structured to include practice in this skill. Students should become familiar with information access tools, libraries, journals, computer data bases, standards and other information sources. It is important that students develop the skill, confidence and desire to acquire and assess needed information and advice from other disciplines, whether the source be technical, social, legal, financial or business.

- Another important skill is that of effective communication. Design exercises provide an excellent opportunity to develop this skill through written reports and through the presentation and discussion of design results with a group of peers and instructors.

- The provision of relevant and contemporary design example material requires an effective means of interaction between engineering professors, engineers in practice and other professionals. It also requires resources to process the experience material into a form suitable for undergraduate use.

- One approach to the development of engineering design skills is the use of case study materials as commonly used in business and management education. Major case studies are probably most appropriate for use in the final year. Mini-cases can, however, be used effectively earlier in the program. Case studies should include design errors, mistakes and accidents as well as successes.

- It is in the nature of a design-based approach to engineering education that the problems presented to students for solution should frequently be of the real kind where some of the information is either insufficient or redundant, and where the art of judgment is required.

RECOMMENDATION 9: The design and presentation of each engineering curriculum should be applications-based, integrating the basic concepts of mathematics, physical sciences, engineering sciences and analysis with their use in modelling, in problem solving, in optimization and in making engineering judgments.

RECOMMENDATION 10: Senior engineering professors who have a broad range of practising experience should be assigned to teach an integrated approach to the fundamental basic subjects in the curriculum.

RECOMMENDATION 11: Engineering faculties should ensure that adequate resources are allocated to provide relevant and contemporary design example material. This requires an effective means of interaction between engineering professors and engineers in practice and also requires resources to process the experience material into a form suitable for undergraduate use.

RECOMMENDATION 12: Design exercises should be structured to include practice in searching out appropriate information using libraries, journals, standards, computer data bases and other information sources.

RECOMMENDATION 13: In structuring the curriculum, adequate provision should be made to develop skills of effective communication through written reports and through the presentation and discussion of design results with a group of peers and instructors.

RECOMMENDATION 14: Professors should give consideration to the increased use of case study materials in the presentation of engineering subjects.

RECOMMENDATION 15: The Canadian Academy of Engineering should take a lead role in establishing a system for the solicitation, preparation and dissemination of suitable case studies on engineering issues, particularly of Canadian origin, for use in engineering education programs.

2.3 Teamwork and Leadership

- Engineers in practice normally work in teams which include complementary skills, experience and specialty. Team members have diverse backgrounds and abilities, and learn much from each other.

- Leadership principles can be taught and leadership skills can be developed through guided experience in team efforts during the undergraduate program.

- The large class sizes and the impersonal examination processes that have become characteristic of most introductory engineering education programs lead to highly competitive attitudes and behaviour by the students. While competition is a reality in the world for which the students are being prepared, it should not be emphasized to the detriment of effective undergraduate education.

- Cooperation among students in problem solving assignments is frequently discouraged in the interests of obtaining an independent evaluation of each student's performance. However, there are good Canadian examples of effective group evaluation.

- Given a reasonably non-competitive environment within a student team, students can do much to educate and assist each other. Teaching a topic is well known to be one of the best means of learning it. Cooperative learning methods have been shown to be highly effective.

- The assignment of a team to a major design project provides a good opportunity to develop cooperation and leadership skills. A team can advantageously include students at various stages in their undergraduate programs and from various engineering disciplines.

RECOMMENDATION 16: The undergraduate program should be designed to develop teamwork and leadership skills through a cooperative learning approach.

2.4 Practical Experience

- Experience of the environment in which engineering is practised is of primary importance in the development of the engineering undergraduate.

- The structure of each undergraduate engineering program should provide opportunity and requirement for practical experience through summer employment, co-operative education arrangements or 12-16 month internship programs.

- Provision of such experience opportunities for undergraduate engineers should be accepted as a responsibility by Canadian industry.

- It is particularly advantageous if the practical experience period for an engineering undergraduate can include opportunity for travel and living in another part of Canada so that perspectives can be broadened and Canadian unity can be promoted.

- Considering the importance of international trade to Canada, the provision of opportunity for many students to obtain experience in foreign countries should be strongly encouraged. Language facility in both English and French should be the norm for Canadian engineers and ability in foreign languages should be encouraged.

RECOMMENDATION 17: Each undergraduate engineering program should provide opportunity and requirement for practical experience.

RECOMMENDATION 18: Canadian industry should progressively and collectively accept ongoing responsibility for providing adequate opportunities to engineering students for practical experience.

RECOMMENDATION 19: Industry and governments should devise incentives to encourage engineering students to seek experience in various regions of Canada and in foreign countries.

2.5 Length of Undergraduate Programs

- An undergraduate program, presented in eight 4-month teaching terms over a period of 4 or 5 years, and including appropriate periods of practical experience, continues for the present to meet the immediate needs of a majority of the current employment opportunities open to new graduates.

- Past experience has shown that such a 32-month teaching program can instill a set of concepts, attitudes, skills and habits that become the most important continuing attributes of an engineer.
- For a number of graduates, this 32-month teaching program followed by appropriate experience and additional continuing education while employed in industry will continue, for the near future, to be an appropriate route to professional qualification.

- Curricular measures proposed in this report to broaden the fundamental base and provide more design emphasis will restrict the amount of advanced material which can be included in an undergraduate program of the present length. Increasing the length of each of the teaching terms is questionable as it would decrease the opportunity for practical experience during the undergraduate years. Addition of another year to engineering undergraduate programs is considered to be impractical as it requires a major step increase in resources.

- As engineering continues to become both more holistic and more advanced, there will be an increased demand for graduates who have more formal education than can be included within the present time constraints. It is proposed that a flexible approach to the evolution of engineering education in Canada be built on a continuation of undergraduate engineering programs of the present length followed by entry of an increasing number of bachelor's graduates to an array of one-year professional masters programs to be described in Section 3 of this report.

RECOMMENDATION 20: The present length of undergraduate program (32 teaching months) leading to a baccalaureate degree in engineering should be retained.

2.6 Accreditation

- The accreditation criteria of the Canadian Engineering Accreditation Board (CEAB) of CCPE for undergraduate engineering programs in Canada include requirements for the equivalent of one term of basic sciences, one term of mathematics, four terms of engineering sciences and design of which at least one term must be engineering sciences and one term design, and one term of social sciences and humanities. A term includes about 13 weeks of instruction plus time for examination, ie.,approximately 4 months.

- While the content requirements and proportions of the curricula are appropriate, an over-emphasis on the use of time-based numerical criteria by accreditation teams or by engineering faculties can mitigate against the appropriate integration of sciences, mathematics, and problem solving experiences including their social and environmental concerns into a design-oriented approach to curriculum presentation.

- Curricula and course descriptions usually emphasize the information content of courses rather than the educational objectives to be achieved. The accreditation process should rely heavily on measures of desired achievement of objectives as seen in the students rather than measures of the reported content.

RECOMMENDATION 21: The Canadian Engineering Accreditation Board should place its primary emphasis on criteria which depend on measures of the quality of the teaching staff, the quality of the learning environment and the quality of the attributes, skills and knowledge acquired by the undergraduate engineering students. The requirements for an appropriate mix of information content should be retained but given secondary emphasis.

3. POSTGRADUATE EDUCATION and RESEARCH

- As we look to a future in which engineering operations involve increasingly complex technical developments as well as increased concern with social, economic and environmental dimensions, the acquisition of a four-year undergraduate degree plus two years of engineering experience will come to be considered inadequate for professional qualification and effectiveness. Additional time for formal education will be required by many students to reach an appropriate level for entry into full professional engineering employment.

- Much of the future wealth of Canada will have to be created by the establishment of new industries based on the exploitation of newly-emerging technologies and new markets. Many of these small- and medium-size industries will not be in a position to provide the new graduates they employ with the necessary additional specialized education, experience and training required in their operations.

- A major objective of postgraduate programs should be the development of persons who can contribute to the creation and growth of the entrepreneurial enterprises on which society depends for new high quality employment and for creation of new wealth.

- At present, a majority of the students enroled in master's programs in engineering in Canada are in programs which are research oriented. This research emphasis has been promoted by several factors: the availability of scholarships for students in research-based programs, the funding of the research of engineering professors including support for the graduate students employed on the research, a requirement that a research-based masters precede doctoral studies, and an image that a research-based masters is superior to a professional masters degree.

- The limited numbers of graduates of these research-based master's programs have made major contributions to the engineering profession and to industry. Their involvement with a research project and their close association with their supervising professor have combined to provide a valuable opportunity for intellectual growth. However, these research-based masters programs have frequently included a research project of such a magnitude that the length of the program has become 5 to 6 terms.

3.1 Professional Master's Programs

- Canadian engineering faculties should plan to provide an array of professional master's programs each requiring about 3 terms or one calendar year of full-time-equivalent study.

- Professional master's programs should be designed to meet identified needs of the major career paths of engineering graduates: engineering design and manufacturing, engineering management and engineering research and development. Some universities might provide professional master's programs to meet specific needs of important sectors of Canadian industry.

- Each professional master's program should have breadth in content. Many should be interdisciplinary.

- Each of these master's programs should be presented at a similar level of intellectual challenge.

- The entrance requirements for all of these master's programs should be the same and should be similar to those of other professional programs in universities such as management and law.

- With the availability of these master's programs and the progressive evolution of Canadian industry, it is expected that, in the future, a majority of engineering graduates will proceed to a master's degree either immediately on graduation or following a period of engineering experience.

- In time, as the proportion of graduates achieving a master's degree increases, a professional master's degree may become a requirement for full professional qualification.

- It should be made convenient for students to enter these postgraduate programs at a career stage when the experience would be most valuable. For a program in engineering management, this might optimally be at about five or more years after graduation. For an engineering design program, it might follow the undergraduate studies or might follow a period of industrial experience. For those in engineering research programs, it is frequently opportune to enter immediately after graduation.

- To meet the needs of those engineers employed in industry, it is desirable that there be opportunity to take these master's programs on a part time basis, either in short periods of a few weeks duration or in late afternoon, evening, weekend or short-course sessions. In some localities, it may be desirable to present courses at a convenient industrial site rather than on university premises.

- In some institutions, it may be desirable to institute combined Bachelors/Masters programs, integrating the professional masters content with the undergraduate studies.

RECOMMENDATION 22: Canadian engineering faculties should plan to restructure their graduate studies to introduce or expand appropriate postgraduate professional master's programs.

RECOMMENDATION 23: Each professional master's program should be designed to meet identified needs in one of the major career paths of engineering graduates: engineering design and manufacturing, engineering management, and engineering research and development. Some programs might be focused on the needs of a specific sector of Canadian industry.

RECOMMENDATION 24: Each professional masters program should be about 3 terms or one calendar year in duration.

RECOMMENDATION 25: Each of the professional master's programs should be presented at a similar level of intellectual challenge.

RECOMMENDATION 26: The arrangements and funding support for these professional masters programs should be such as to make them convenient for students to enter when the experience would be most valuable. Also access to the programs by part-time students should be facilitated.

RECOMMENDATION 27: In designing the professional masters programs, emphasis should be placed on developing engineering graduates with the appropriate attributes and potential to play a major role in establishing new enterprises, restructuring existing processes and developing new products and services.

3.1.1 Master's in Engineering Design

- In this context, the term "engineering design" should be interpreted very broadly to include courses and projects in the design, manufacture, production, operation and servicing of processes, devices or systems.

- Graduates of a four-year undergraduate engineering program are currently not adequately prepared to meet the needs of many industries. This is particularly true in small and medium advanced-technology industries which have limited in-house education and training facilities.

- The needs for additional formal education in specialized technologies will be increased when measures are taken to broaden undergraduate educational programs.

- Provision should be made for a considerable involvement of practising engineers in the presentation of these master's programs. Adjunct engineering professors can play a major role in supervising design projects as well as presenting course material on design methodology and specialties.

RECOMMENDATION 28: Engineering faculties should design and provide one-year professional masters programs in Engineering Design, coordinated with their revised undergraduate programs, interpreting the term "design" very broadly to include advanced-level courses in technical specialties and projects in the design, manufacture, production, operation and servicing of processes, devices and systems.

RECOMMENDATION 29: Highly qualified practising engineers should play a major role in the presentation of design-oriented master's programs.

3.1.2 Master's in Engineering Management

- Engineering Management links the disciplines of engineering and management so as to plan and implement technological capabilities to accomplish the objectives of an organization. It integrates the technology of an activity with the management of the activity.

- In the past, a significant number of engineers have undertaken postgraduate studies for a Master of Business Administration (MBA) degree, often after a number of years employment and at a stage when they were acquiring some management responsibility. It is the view of many in industry that the needs of many engineers could be met adequately, and potentially better, by a postgraduate program shorter than the two-year MBA and including a mixture of management and technical subjects appropriate to engineering industry.

- Some valuable experience in addressing this market has been gained from several 5-year undergraduate programs combining an engineering discipline with management. With the proposed broadening of undergraduate programs, and the expectation that many will wish to enter management studies sometime after initial employment, it is considered that a one-year postgraduate program is an effective way of providing education in engineering management.

- Close cooperation of professors in engineering with those in management will be needed to develop and present the programs in engineering management. An important byproduct to be expected of this cooperation is a broadening of outlook by both engineering and management staff.

- Special consideration should be given to inclusion of foreign language studies in engineering management programs.

- The establishment in 1989 of a program of Chairs in the Management of Technological Change jointly by the Natural Science and Engineering Research Council and the Social Science And Humanities Research Council in partnership with industry provides an important initiative and resource for this professional master's program.

RECOMMENDATION 30: Engineering faculties should cooperate with Management faculties in designing and presenting one-year professional masters programs in Engineering Management.

3.1.3 Master's in Engineering Research and Development

- This program combines courses in advanced technologies with an opportunity for some research experience, while retaining the breadth appropriate for professional master's studies.

- With the proposed broadening of the undergraduate engineering programs, some specialized subjects now in the undergraduate curriculum may be presented for the first time at this graduate level.

- This program is particularly suited for those students who contemplate a research-oriented career in industry, specialized research laboratory or higher education. It provides an early testing period before entering doctoral studies.

- While this program will provide an introduction to engineering research, it is not intended to produce an independent researcher. It is proposed that the first fully research-based degree become the doctorate.

RECOMMENDATION 31: Research and development oriented masters programs should be continued but should be designed for completion in about 3 terms or one year full time.

3.2 Doctoral Studies in Engineering

- The doctorate is the highest level of formal engineering education. Ideally, it should provide graduates who combine a depth of scientific understanding and research capability with a breadth of innovative applicational ability.

- At present, many engineering doctoral theses are deeply specialized and narrow in scope, whether analytical or experimental. The prime emphasis is on an original contribution to knowledge. Less frequent are theses which are synthesis or design based, discovering and elaborating novel operational principles in applications of existing knowledge in a complex holistic situation.

- The objectives of doctoral programs in engineering should include, not only the development of new and significant contributions to engineering knowledge, but also the development of superior capabilities in the candidate for synthesis, innovation, technical judgment, economic and social sensitivity and leadership. To emphasize these objectives, some institutions might consider adopting the designation of a Doctor of Engineering (D.Eng.) degree.

- Doctoral students should be involved in an understanding of the whole process of generating and defining the problem, negotiating collaborative agreements for contributions, designing and performing experiments, and implementation of results, including the intellectual property aspects of technology transfer from university to industry.

- Entry to an engineering doctoral program should normally follow the successful completion of a professional master's program. Prior research experience should not be a requirement.

- Most if not all doctoral candidates in engineering should develop close links with counterparts in industry during their programs. The vertical or sequential model of the university discovering and then the industry applying is not appropriate for most current engineering. Rather, a horizontal model involving close university-industry interaction is needed.

RECOMMENDATION 32: Doctoral programs in engineering, while research oriented, should aspire to achieve a balance between the development of new and significant contributions to engineering knowledge and the development of superior capabilities in the candidate for innovation, and technical judgment.

RECOMMENDATION 33: Regulations should be such as to allow admission to an engineering doctoral program following completion of any of the professional masters programs.

RECOMMENDATION 34: Research supervisors should encourage doctoral candidates in engineering to develop close links with counterparts in industry during their programs.

3.3 Engineering Research, Development and Design

- In universities, the processes of engineering education and of engineering research are closely linked and interdependent. Most fields of engineering are in rapid evolution and change. A sensitivity to what is happening at the frontiers of both the sciences and the marketplaces is necessary for the evolution of relevant engineering educational curricula and programs. Involvement in research and development projects is therefore a valuable aspect of the formation of competent engineers.

- Involvement in depth in a project of research has proven, over many decades, to be a means of developing superior engineering attributes in Master's and Doctoral students. The environment for undergraduate students is also influenced markedly by the involvement of the professors and the graduate students in research.

- Policies and practices relating to engineering research have been explored in some depth in a companion report, "Engineering Research in Canadian Universities" [1]. The thrust of that document can be summarized in the following excerpt where the Academy suggests that the universities consider the following:

- ...a dedication by engineering professors to contribute to the solution of the present and future problems of Canadian society that fall within the broad scope of the engineering profession..... Since engineering research must be oriented toward eventual application, it is proper that Canadian engineering professors choose to direct their efforts and those of their students mainly toward areas with Canadian needs and future opportunities in mind. The impact of this engineering research may however be made international through the efforts of Canadian companies and consultants working in an international context.

- The researches undertaken by engineering professors and their graduate students should be directed at real and relevant issues so that significance of the work to society, both now and in the future, is evident to the educational, industrial and governmental communities.

- Some have suggested that the two primary roles in the university of teaching and research are separable, even to the extent of having distinct research professors and teaching professors. This policy would be particularly inappropriate for engineering. Engineering is a profession dedicated to serving society through the application of knowledge and skill gained from a variety of academic disciplines, from research in its own engineering disciplines, and from engineering practice. Emphasis in the profession is focused mainly on the integration of available knowledge to achieve useful ends. It is important that the undergraduate and postgraduate education of engineers take place in an environment that is permeated with all elements of this philosophy of the profession. Close integration of research and teaching is essential in this process.

RECOMMENDATION 35: Professors and their graduate students should choose their research, development and design projects with a view to their relevance to the solution of present and future problems and opportunities of Canadian society.

4 . LIFELONG PROFESSIONAL EDUCATION

- The education and formation of an engineer is not at all complete upon graduation from an undergraduate engineering program or even from a graduate program.

- The needs for further education, both formal and experience based, will be increased when action is taken to broaden the undergraduate programs.

4.1 Programs for Engineers in Training

- For most engineering graduates, the undergraduate program should be followed by a planned training program in industry, a professional Master's program, or preferably by both.

- Ideally, engineering industry should provide formal development programs for Engineers-in-Training in much the same manner as legal firms, accounting firms and medical hospitals provide for their future professionals.

- It is recognized that many industrial companies are not capable of providing a comprehensive development program for Engineers-in-Training. For these, a mentorship program should be established. Also, industry leaders should give consideration to the organization of consortia of companies to provide, in cooperation with universities, appropriate experience and education for Engineers-in-Training.

- During the years between graduation and professional registration, a reasonable fraction of the available time of the Engineer-in-Training should be allocated to relevant continuing education.
- The profession and industry should consider the adoption of salary scales which recognize the obligations of the employer for contributing to development during the training period and which later provide substantial salary increase in recognition of the achievement of professional status.

- The Canadian Council of Professional Engineers and its Associations should give consideration to an extension of the years of experience requirement before registration and to a more formal specification and scrutiny of the content and quality of the training process.

RECOMMENDATION 36: The Engineering Profession in Canada should consider introducing a more formal and longer (eg. four year) experience requirement for Engineers-in-Training prior to registration.

RECOMMENDATION 37: Engineering industry should plan to provide adequate development programs for Engineers-in-Training including the appointment of capable mentors. Small and medium size engineering employers should consider establishing consortia to meet mutual needs in providing such programs.

4.2 Continuing Education for Professional Engineers

- The rapid changes which are occurring in all aspects of engineering require that each professional engineer have a program of continuing education and updating of expertise.

- Each program should be designed, not only to maintain and extend the area of current employment expertise, but also to maintain a sufficient breadth to adjust to potential changes in technology, markets or career path.

- Continuing education for professional engineers may include a wide range of activities such as technical conferences, independent study, in-house courses, seminars, formal graduate courses, workshops, correspondence courses.

- The subject matter of appropriate continuing education activities may be in a wide range of areas such as science, technology, management, the environment, the economy or the society.

- The primary responsibility for maintaining professional competence rests with the individual engineer.

- Each professional engineer should play an active role in an appropriate technical society.

- Employers should accept some responsibility for maintaining the competence of their professional engineering employees. Much has been invested in these people. An enlightened policy might provide for at least 5% of the employed time to be allocated to continuing education activities. This can not only protect that investment but also provide a high return.

- Engineering faculties and technical societies should cooperate in providing specialized courses for practising engineers using a variety of media such as video lectures and demonstrations, television programming, satellite transmissions, and designated distinguished lecturers.

- Groups of companies with similar interests should consider forming consortia to mount suitable continuing education programs in cooperation with universities, technical societies, manufacturers associations and consultants.

- Governments should recognize that upgrading of our current engineering workforce is critically important in addressing the issues of competitiveness and sustainability. The provision of infrastructure to deliver continuing education programs would be a prudent investment. Also, tax incentives might be considered.

- Professional engineering associations in Canada should consider introducing a formal requirement for evidence of appropriate education and development activity by each engineer as a condition of continued registration.

RECOMMENDATION 38: Each professional engineer should have a program of continuing education and updating of expertise, including an active role in an appropriate technical society.

RECOMMENDATION 39: All employers should provide opportunity, encouragement, allocation of time and financial support for appropriate programs of maintaining the competence and flexibility of their professional engineering employees.

RECOMMENDATION 40: Professional engineering associations in cooperation with technical societies, universities and industrial organizations should introduce a program of recognizing participation in appropriate continuing education activities by professional engineers, with a view to making adequate participation one element in a review process required for continued professional registration.

5. STEPS TOWARD IMPLEMENTATION

- The significant changes that are required in the industrial and social cultures of Canada to meet the challenges of the present and the future must be accompanied by appropriate changes in attitudes, policies and practices, not only of engineering professors, students and educational administrators, but also of many in industry, government and the profession.

- This section of the report examines some of the current impediments to achieving the desired educational objectives and suggests actions which can provide the opportunities and incentives to promote the appropriate evolution.

- Continued acquisition of the resources to provide good engineering education is dependent on the firm support of the public and its governments, prospective students and industry. It is therefore imperative that educators of engineering students dedicate themselves to the primary task of meeting the needs of the roles for which their engineering students are being prepared.

- Some of the current expectations of engineering professors and some of the pressures that they experience in their universities must be changed if the desired changes are to occur in undergraduate and graduate engineering education.

- The recruitment processes of universities ensure that persons appointed to the professorate are highly intelligent and highly motivated. Most will succeed according to the rules for success as they perceive them. Therefore, the incentives built into the system and presented to the professors are of paramount importance.

- Currently, major influences on the attitudes of engineering professors arise from the needs of their own research programs. It is perceived that it is predominantly on the results of these researches published in archival journals that their careers depend.

- The evolution of effective engineering education can be expedited and promoted by developing closer and continuing links at the working level between educators and practitioners. Incentives are needed if engineering professors are to allocate any significant part of their time to this activity.

RECOMMENDATION 41: Engineering faculty administrators should ensure that the incentives experienced by professors are consistent with the primacy of effective education as an objective of their faculties.

5.1 Evaluation Criteria and Practices

- With few exceptions, engineering education and its associated research in Canada occurs in multi-faculty universities. Engineering professors and students are therefore subject to the general policies of these universities. The ability of engineering faculties to carry out their education and research objectives is constrained by some of these policies and practices.

- Universities have set up policies and processes to measure the quality of professors. Criteria, common to all disciplines, are established for the initial recruitment of faculty, for the review prior to achievement of academic tenure and for promotion to full professorship. These evaluation criteria normally include performance in both teaching and research, and may also include an assessment of creative professional accomplishment.

- Although the policies of many universities may call for equal weight to be given to teaching and research in the evaluation of professors, accomplishment in research has been perceived as the dominant factor in practice in many institutions.

- A major practical reason for dominance of research over teaching in evaluation is that research efforts are normally well documented as an essential and funded part of the research process and can readily be measured by the acceptance of research papers in properly reviewed journals. Education is arguably the university's primary role. However, documentation of educational accomplishment, is much more subjective and therefore more difficult.

- Evaluation criteria tend to be dominated by the values of the majority in the university, i.e. those in the basic sciences, the arts and the humanities. It is frequently difficult in the university community to argue successfully for criteria suited to the character of those disciplines which have professional objectives.

- In the pure sciences and in much of the arts and the humanities, research and scholarship are characterized by an emphasis on contributing to basic specialized knowledge in an academic discipline. In contrast, the emphasis in engineering research should be, and, at its best is, directed at a contribution to the solution of a real or perceived problem or opportunity in society.

- In universities that have included in their policies an evaluation category of creative professional accomplishment, major difficulties arise in providing documentation of such accomplishments acceptable to university committee personnel who are frequently not familiar with the profession.

- Experience in an environment of engineering practice has long been advocated as a desirable, if not essential, attribute of a prospective engineering professor. However, this is not a concern that is shared by most university disciplines and understandably is not reflected in recruitment criteria and starting salaries.

- To understand the effect of these university pressures, it is important to recognize that those being recruited to professorships in engineering are very able people who generally have outstanding academic records. They expect to succeed in their new roles and, accordingly, they act within the existing rules to advance their chances for success. If this process does not produce the desired results, the fault lies not with the junior professors, but rather with the rule makers and the systemic preconceptions in applying the rules.

- In evaluation, significant weight should be given to the contributions that the professor has made to the planning, management and administration of the educational process. The preparation of good curriculum proposals, the preparation of good educational materials, software and laboratory experiences, the writing of good educational papers, the successful training of teaching assistants and junior professors should all be considered to be of significant value.

- Input from recent and mid-career graduates should form a significant part of the documentation assembled for evaluation. This input can be particularly useful in assessing the success in inculcating concepts and habits of approach which have proved to be of lasting value.

- Input from senior professorial colleagues who have professional engineering experience is of particular value. If the integration processes in the curriculum are effective, these colleagues will have useful knowledge of the attitudes, approaches, skills, strengths and weaknesses of their more junior staff members.

- Student evaluations of teaching performance are useful in assessing such factors as effectiveness of preparation, organization, presentation, communication, assistance of individuals and the choice of educational materials.

- The processes of evaluating research accomplishments have been highly developed to serve the needs of the research funding agencies and are therefore readily available to the universities for their own evaluations. The main input comes from other researchers in the same specialty area who advise on the acceptability of research papers submitted for publication. The existence of a published paper is only a measure of having reached a standard for acceptance by the research journal. It is not an effective measure of relevance to persons outside the specialty research group such as potential users of the results.

- Useful input on the relevance and value of the research contributions of an engineering professor can be obtained from qualified persons in industry who have direct knowledge of the results and impact of the research.

RECOMMENDATION 42: Universities should recognize that the objectives and responsibilities of professional faculties such as engineering are somewhat different from those of other disciplines.

RECOMMENDATION 43: Universities should ensure that their recruitment and advancement criteria for professors are sufficiently broad to include the special needs of engineering faculties. These criteria should include appropriate recognition of teaching performance, research development and design contributions, professional experience and accomplishments, service to the community, and contributions to the planning, management and administration of the educational process.

RECOMMENDATION 44: The National Council of Deans of Engineering and Applied Science (NCDEAS) should develop an appropriate set of criteria guidelines for initial recruitment of engineering faculty, for the achievement of academic tenure and for promotion to full professorship.

RECOMMENDATION 45: In the application of advancement criteria for engineering professors, universities should give significant weight to input from persons who have a good understanding of the nature and needs of the graduates and the profession: practising professional engineers, recent and mid-career engineering graduates and senior professorial colleagues with appropriate engineering experience.

5.2 The Influence of Research Policy

- Research in engineering faculties should have two closely related objectives: the production of knowledge useful to the present or future practitioners of the profession of engineering, and the enhancement of the quality and capability of both undergraduate and graduate students.

- The emphasis on recruiting new professorial staff tends to be focused on the quality of the doctoral research which normally precedes faculty appointment. The initial emphasis for a newly appointed professor is on continuing the high rate of research production which typified the postgraduate education period in order to ensure the granting of tenure and a continued growth of research funding. This can most readily be achieved by continuing in the same problem area as was addressed in the doctoral research.

- In the current environment, a junior engineering professor looking forward to a successful and stable university career would be ill-advised to allocate much time to interaction with the profession, with industry, and with the user communities. Consulting, which is recognized as an excellent means of useful interaction, may be discouraged by this environment, particularly in the important early years because it does not usually lead to publishable results.

- Undue emphasis on the production of early research results following appointment must be avoided. Newly appointed professors should have adequate opportunity and incentive to broaden their engineering knowledge and experience, and to plan the direction of their future research on the basis of the relevant issues that they encounter.

- Much of the research funding for Canadian engineering professors should be dependent on the potential contribution to issues of national importance to Canada. This approach provides direct incentive for professors to make relevant contacts with the user community and interact with this community in developing research contract proposals.

- The assessment of relevance and value of a professor's research should be based to a significant extent on the willingness of industry and other user agencies to contribute to the continuing support of the research.

- Research funding agencies should recognize that the output of greatest value from most academic research is people who are highly educated and trained. The quality and quantity of this output should be seen as a major factor in fund allocation.

- For engineering professors, NSERC research grants provide base funding for the exploration of new ideas on the results of which targeted contract funding can be sought. Accordingly, a broad base of funding is preferred for engineering disciplines. In the interests of an adequate supply of graduates with advanced-level education, most if not all engineering professors should be directing the work of several graduate students. All of these engineering professors involved in research and graduate supervision should receive some sustaining support. Most universities have not been in a position to provide such support from their base budgets in recent years.

- There is a need for the introduction and extension by the funding agencies and by government departments of programs which encourage linkages between engineering professors and Canadian industry in the conduct of joint research. An excellent example is the Cooperative Research and Development (CRD) grant program of NSERC. Also, the establishment of federal and provincial Centres of Excellence has provided useful experience for extension of this approach in the future.

- It should be recognized that incentives are needed to attract both engineering researchers in universities and personnel in industries to undertake cooperative projects. It is an appropriate role for governments to provide such incentives. These incentives must be strong enough to encourage approaches to universities by companies who have no previous history of such interaction, and, in some instances, no previous involvement in research and development. A major criterion for support should be the willingness on the part of both the professor and industry to devote time and resources to the project.

- Governments should recognize that a major share of the funding for engineering research projects carried out jointly by engineering faculties and industries must come from resources provided by these governments. Large research-oriented firms can and do provide substantial research support, but these firms are few in number in Canada. The financial investment that most of our smaller emerging advanced-technology industries can be expected to make for this type of research is limited. A small financial contribution by an industrial firm together with involvement of its staff provide both a valid measure of its commitment and an assurance of effective transfer of technology.

RECOMMENDATION 46: Engineering faculty administrators should ensure that newly appointed professors have adequate opportunity and incentive to plan a relevant research program and to establish good contacts in industry.

RECOMMENDATION 47: Much of the research funding for engineering professors should be based on the potential contribution to issues of national importance to Canada.

RECOMMENDATION 48: Agencies such as NSERC, NRC and government departments should establish, expand and emphasize programs supporting cooperative research and development by industry and universities.

RECOMMENDATION 49: In evaluating proposals for cooperative research and development involving industry and universities, granting agencies should place emphasis on the willingness of industry to contribute time and funds commensurate with their available resources.

RECOMMENDATION 50: Research funding agencies should recognize that the output of greatest value from most academic research is highly educated and trained people.

5.3 Incentives and Policies in Teaching

- The rewards for good teaching performance must be made as attractive than those for good research. Enhanced means must be found to recognize and reward outstanding teachers. Surveys of past graduates show that the influence of certain outstanding teachers is the predominant factor in their assessment of the value of their university education.

- There are many national and international awards accessible to professors for superior research performance. These are highly publicized and the winners of such awards are regarded as the stars of the university. Similar prominence should be given to awards for excellence in teaching.

- The introductory courses for engineering students should be taught by the best and most experienced professors. These are the people who should have acquired the greatest breadth of knowledge, the widest experience, the best command of fundamental concepts, and the greatest sensitivity to the essence of engineering design and practice. Most of those meeting the desired criteria are likely to be within the engineering faculties.

- In most universities, the responsibility for teaching the basic sciences and mathematics to undergraduate students rests with departments outside the engineering faculty. While the students have been admitted directly to engineering programs, their effective contact with engineering may be delayed by a year or more, leading to potential loss of the motivation which attracted them to engineering. This practice also tends to perpetuate the linear unintegrated approach to engineering education discussed earlier.

- Many engineering courses for senior and postgraduate students can be taught competently by junior professors or by adjunct professors from the external community. These are persons who are likely to have state of the art knowledge of the material. At this stage, the students are already familiar with most of the language, conventions, habits and concepts of their engineering discipline. The demands on the instructor for breadth of knowledge and teaching experience are less. The classes are smaller and dialogue is easier to encourage. The environment and the audience is more forgiving of teaching shortcomings.

- At present, many professors prefer assignment to a specialized subject in the senior year of the undergraduate curriculum as this facilitates recruitment of good graduate students.

RECOMMENDATION 51 Engineering faculties should ensure that the rewards for good teaching are made as attractive as those of good research.

RECOMMENDATION 52: Recognizing the importance of knowledge, skill and broad experience in teaching an introductory course for engineering students, engineering faculties should make such an assignment a mark of career accomplishment for a professor.

5.4 Professorial Experience and Interaction

- It is highly desirable for engineering professors to be recruited from industry after some years of effective experience. Engineering faculties in Canada have had only limited success in such recruiting.

- Several factors mitigate against the industry-to-university career route for engineering professors:

- the desire by new engineering doctorates to continue with their researches,

- the fact that starting salaries for engineering professors are generally lower than for counterparts in industry,

- the standard requirement of universities that professors have doctorates prior to appointment,

- the risk in leaving an industrial position for a somewhat uncertain continuity of career in the university until tenure is achieved,

- the attitudes within the university regarding those who are proposed for faculty status with only a limited publication list.

• Industrial postdoctoral fellowships provide a good approach to industry for new doctoral graduates and are of sufficiently limited length that subsequent university recruitment is feasible.

• An effective means of providing engineering professors with useful and varied practical experience is through consulting arrangements with industry. Through this means, engineering professors can practice their profession on a continuing part-time basis. Most universities permit professors to spend 10 to 20% of their time on such consulting activity. Junior professors need effective assurance that allocation of time to consulting will not jeopardize their advancement prospects.

• Research contracts can be highly effective in building interaction between professors and industry.

• There should be encouragement and assistance by engineering faculties for professors to spent their sabbatical research and study leaves in industry.

• Industry can help by providing appropriate opportunities for research and study leaves and by providing some financial support to the professor during such leaves.

• One of the difficulties professors perceive in spending a prolonged period away from the university on leave is the potential disruption of their ongoing research programs and the break in continuity of the supervision of their graduate students. Provision for regular return visits to the university can assist in this.

RECOMMENDATION 53: Engineering faculties should formulate and gradually establish a policy of recruiting a majority of their professors after some years of effective engineering experience.

RECOMMENDATION 54: Granting agencies should expand their industrial postdoctoral fellowship programs.

RECOMMENDATION 55: Engineering faculties should provide encouragement and assistance for their professors to spent their sabbatical research and study leaves in industry.

RECOMMENDATION 56: Industry should provide appropriate opportunities for the employment of engineering professors during their research and study leaves.

RECOMMENDATION 57: Engineering faculties should encourage involvement of their engineering professors in appropriate consulting arrangements with industry and with other users of engineering services.

5.5 Professorial Workload and Time Allocation

- In recent years, the pressures on engineering professors have increased substantially. These pressures are partly the result of reduced education funding per undergraduate student necessitating greater teaching loads, and partly due to increased concern for research output and for the funding which accompanies research grants and contracts. These pressures have resulted in insufficient time for preparation of course material, larger undergraduate classes, less personal contact between each individual student and the professor. It is important that this trend be reversed so that an appropriate level of quality can be maintained in the education of engineering undergraduates.

- One aspect of time pressure on university professors is the need to prepare extensive documentation for competitions in the research funding agencies. For engineering faculties, some of this time can be more effectively used if a significant part of total engineering research and development funding is routed through the user community, mainly in industry. Under this approach, the incentive for the professor is to allocate time in establishing effective contacts with industry. Given the willingness of the industrial partner to provide some financial and time support for the proposed research, the review process can be simplified to an assurance from an external assessor that the proposal meets the program criteria of content and quality.

RECOMMENDATION 58: Universities should ensure that the staff-student ratio in engineering faculties is sufficiently large to provide the individual attention which is necessary for adequate professional education.

6. RESOURCES FOR ENGINEERING EDUCATION

- Canada's future wealth and prosperity will depend in large measure on the incorporation of superior skill, intelligence and added value into its products and services.

- High quality job creation is a priority for the years to come. Professional engineers can play an important role in establishing new enterprises, restructuring existing processes and developing new products and services. Emphasis should therefore be placed on developing graduates with the appropriate attributes and quality for this innovative role as well as producing graduates fitted primarily for existing employment. A person who has been instrumental in creating new and valuable jobs should be regarded as having made an important contribution to Canada.

- Engineers are employed in large numbers in the wealth producing and export industries. In the future, as our reliance on our natural resource exports reduces, a larger part of our exports will have to be in the form of manufactured products, industrial processes and services with a high intellectual or value-added content. This will require more engineers particularly in the more highly qualified categories.

- The significant role of engineers in the solution of environmental issues should not be overlooked in assessing the value of engineering education to society. While others may take a lead role in identifying issues and inducing public concern, engineers will play the lead role in developing appropriate solutions.

- Adding emphasis and resources to engineering education may add substantially to the future health and security of our universities. In the past, public support and confidence was influenced by the belief that a university degree would guarantee employment, even if the courses taken were not directly preparatory for a particular job market. Employment opportunity has now become much more dependent on the capacity to produce wealth. Strengthening a wealth and job-producing professional faculty such as engineering is a strategy which can restore and build public confidence in the relevance of the university and its great value to the community.

6.1 Public Investment in Engineering Education

- Major adjustments in the policies and approaches of governments on the funding of both education and research are required if the changes advocated in this report are to occur. The breadth, quality and relevance aspects of university education need to receive more emphasis in funding allocation.
- The general value of higher education is not in question. However, considering the present state and future of our economy, not all higher education is of equal value to the country. There is a strong case for giving engineering education a sufficient priority through targeted funding so that we can be assured of the means to produce the wealth required to fund other desirable social and environmental initiatives.

- At present, the provision of targeted funding for engineering is inconsistent with the funding mechanisms established for universities by most provincial governments in Canada. Normally, funds are provided to each university on a formula basis. The allocation of funds to each faculty is then determined by the central university administration. There are, however, precedents for the provision of targeted funding by governments. For example, education for the medical profession receives substantial financial support through the major role played by publicly funded hospitals in training for medical students, interns and fellows. Also, for example, the government of Quebec has allocated funds specifically for engineering teaching equipment.

- In recent decades, emphasis of public educational policy has been placed on increasing accessibility to universities. Regrettably, this has not always been accompanied by the provision of adequate resources. For the profession of engineering, maintenance and enhancement of education quality is imperative. The numbers of students admitted should be regulated to match the resources which are made available.

- Engineering technologists play important roles which are complementary to those of professional engineers. Sufficient resources should be provided so that community colleges can produce adequate numbers of engineering technologists from programs which are coordinated with those of university engineering faculties so as to optimize their complementary roles.

- The federal government plays a substantial role in the funding of research. It would be highly desirable if an enhanced country-wide support of engineering education could be devised through federal-provincial agreement, justified on the basis of its high national importance.

RECOMMENDATION 59: Since much of the activity of engineers is wealth producing, Canadian governments should formulate public education policy to give priority to ensuring an adequate supply of qualified entrants to the engineering profession by providing appropriate targeted resources in support of both engineering education and research.

6.2 Funding by and for Students

- Provincial governments have promoted a policy of wide accessibility to university education. This policy has usually been accompanied by severe restrictions on the tuition fees which universities have been allowed to charge to students, based on an assumption that higher fees would restrict accessibility.

- Undergraduate engineering students have demonstrated, in several universities, that they are willing to pay increased fees in order to ensure the quality of their education. Even in a time of economic recession, many engineering students have voted to continue voluntary contributions.
- In general, there has been no shortage of qualified applicants for undergraduate engineering programs in Canada. Accordingly, a significant improvement in funding for engineering could be achieved if provincial governments would permit universities to have freedom in setting fee structures for individual undergraduate programs on the understanding that these funds would be routed to the appropriate faculties.

- For those for whom higher fees might be a serious impediment to entering engineering, loan programs with repayment after graduation through the income tax system are appropriate.

- At present, full-time graduate students in engineering receive financial support from scholarships, research assistantships and teaching assistantships. The proposals in this report for the establishment of professional masters programs raise some issues regarding the financial support of these graduate students.

- Students enroled in full-time, professional masters programs will have a very heavy academic load and will have only limited time available to undertake teaching assistantships. For these students, the funding implications for the professional masters year are similar to those of the previous undergraduate years unless appropriate provisions are made.

- NSERC should continue to support graduate students who are registered in the professional masters programs in engineering. Engineering management should be regarded as an integral part of the engineering disciplines.

- For those who are taking a professional masters program on a part-time basis while employed in industry, it is appropriate for the industry to provide both released time and financial assistance. Some industries may be able to provide financial support for selected employees while on full-time programs.

RECOMMENDATION 60: Provincial governments should permit universities to have freedom in setting fee structures for programs such as engineering on the understanding that these funds would be routed to the appropriate faculties. Student loan programs should be provided for those who are qualified but lack the immediate resources.

RECOMMENDATION 61: NSERC should accept a broad view of engineering research to include design, development and engineering management. It should continue to support students registered in any of the professional masters programs.

7. CONCLUDING REMARKS

- This report has recommended major changes to the content, approach and environment of engineering education in Canada. Implementation of these proposals is a formidable task requiring a major cultural evolution, not only in the universities but also in industry and in government.

- The Academy recognizes that currently available resources are inadequate to implement many of the recommendations at this time. The intention of this report is to provide a vision of where we ought to be so that each step of pressure and progress can be toward that goal.

- There is no standard rigid formula for the Canadian engineering education system of the future. Rather there must be a spirit of focused experimentation based on some of the objectives which have been formulated. A diversity in the local result should be expected and welcomed.

- The Canadian Academy of Engineering, together with the Canadian Council of Professional Engineers and the National Council of Deans of Engineering and Applied Science, can do much to establish an enhanced image of the profession of engineering, not only with the general public but also in the profession itself. The respect and value accorded to the profession depends on the confidence held by the public that engineering is committed to their welfare, that service to the public is paramount and that the ethics of engineering are second to none among the professions.

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LISTING OF RECOMMENDATIONS

1. The Canadian Academy of Engineering, together with other engineering organizations in Canada, should focus efforts on informing the public on the role that the engineering profession plays in the welfare of the country, and on the important distinctions between engineering and science or technology.

2. The Canadian Academy of Engineering should commit itself to an active and continuing role in promoting engineering education of appropriate content and quality, in cooperation with engineering faculties, universities, industry, professional associations, technical societies and governments.

3. Engineering faculties should adopt, as their primary goal, the educational formation of students in preparation for entry to the engineering profession.

4. Engineering faculties should ensure that undergraduate engineering programs are broadly based and holistic in scope, including both those concepts which are fundamental to the discipline and those which are basic to closely related disciplines. Specialization of programs at the undergraduate level should be avoided.

5. The curriculum content should be designed to inculcate those basic attributes - concepts, techniques, skills, habits and insights - that are believed to be of lasting value and applicability. Recognizing that the lifetime of most technical information is short, the rationale for the inclusion of specific information content in the curriculum should primarily be its contribution to development of these basic desired attributes.

6. Engineering faculties should establish and maintain adequate means for obtaining significant and continuing input from engineering practitioners who can reflect the needs of the marketplace.

7. The curriculum should provide for the inclusion of the societal and environmental context of engineering, with both its benefits and negative impacts.

8. The curriculum should include at least one opportunity to undertake a major design task. The selection of this major design should be such as to emphasize a holistic approach.

9. The design and presentation of each engineering curriculum should be applications-based, integrating the basic concepts of mathematics, physical sciences, engineering sciences and analysis with their use in modelling, in problem solving, in optimization and in making engineering judgments.

10. Senior engineering professors with a broad range of practising experience should be assigned to teach an integrated approach to the fundamental basic subjects in the curriculum.

11. Engineering faculties should ensure that adequate resources are allocated to provide relevant and contemporary design example material. This requires an effective means of interaction between engineering professors and engineers in practice and also requires resources to process the experience material into a form suitable for undergraduate use.

12. Design exercises should be structured to include practice in searching out appropriate information using libraries, journals, standards, computer data bases and other information sources.

13. In structuring the curriculum, adequate provision should be made to develop skills of effective communication through written reports and through the presentation and discussion of design results with a group of peers and instructors.

14. Professors should give consideration to the increased use of case study materials in the presentation of engineering subjects.

15. The Canadian Academy of Engineering should take a lead role in establishing a system for the solicitation, preparation and dissemination of suitable case studies on engineering issues, particularly of Canadian origin, for use in engineering education programs.

16. The undergraduate program should be designed to develop teamwork and leadership skills through a cooperative learning approach.

17. Each undergraduate engineering program should provide opportunity and requirement for practical experience.

18. Canadian industry should progressively and collectively accept ongoing responsibility for providing adequate opportunities to engineering students for practical experience.

19. Industry and governments should devise incentives to encourage engineering students to seek experience in various regions of Canada and in foreign countries.

20. The present length of undergraduate program (32 teaching months) leading to a baccalaureate degree in engineering should be retained.

21. The Canadian Engineering Accreditation Board should place its primary emphasis on criteria which depend on measures of the quality of the teaching staff, the quality of the learning environment and the quality of the attributes, skills and knowledge acquired by the undergraduate engineering students. The requirements for an appropriate mix of information content should be retained but given secondary emphasis.

22. Canadian engineering faculties should plan to restructure their graduate studies to introduce or expand appropriate postgraduate professional master's programs.

23. Each professional master's program should be designed to meet identified needs in one of the major career paths of engineering graduates: engineering design and manufacturing, engineering management, and engineering research and development. Some programs might be focused on the needs of a specific sector of Canadian industry.

24. Each professional masters program should be about 3 terms or one calendar year in duration.

25. Each of the professional master's programs should be presented at a similar level of intellectual challenge.

26. The arrangements and funding support for these professional masters programs should be such as to make them convenient for students to enter when the experience would be most valuable. Also access to the programs by part-time students should be facilitated.

27. In designing the professional masters programs, emphasis should be placed on developing engineering graduates with the appropriate attributes and potential to play a major role in establishing new enterprises, restructuring existing processes and developing new products and services.

28. Engineering faculties should design and provide one-year professional masters programs in Engineering Design, coordinated with their revised undergraduate programs, interpreting the term design very broadly to include advanced-level courses in technical specialties and projects in the design, manufacture, production, operation and servicing of processes, devices and systems.

29. Highly qualified practising engineers should play a major role in the presentation of design-oriented master's programs.

30. Engineering faculties should cooperate with Management faculties in designing and presenting professional masters programs in Engineering Management.

31. Research and development oriented masters programs should be retained but should be designed for completion in about 3 terms or one year full time.

32. Doctoral programs in engineering, while research oriented, should aspire to achieve a balance between the development of new and significant contributions to engineering knowledge and the development of superior capabilities in the candidate for innovation, and technical judgment.

33. Regulations should be such as to allow admission to an engineering doctoral program following completion of any of the professional masters programs.

34. Research supervisors should encourage doctoral candidates in engineering to develop close links with counterparts in industry during their programs.

35. Professors and their graduate students should choose their research, development and design projects with a view to their relevance to the solution of present and future problems and opportunities of Canadian society.

36. The Engineering Profession in Canada should consider introducing a more formal and longer (eg. four year) internship requirement for Engineers-in-Training prior to registration.

37. Engineering industry should plan to provide development programs for Engineers-in-Training including the appointment of capable mentors. Small and medium size engineering employers should consider establishing consortia to meet mutual needs in providing such programs.

38. Each professional engineer should have a program of continuing education and updating of expertise, including an active role in an appropriate technical society.

39. All employers should provide opportunity, encouragement, allocation of time and financial support for appropriate programs of maintaining the competence and flexibility of their professional engineering employees.

40. Professional engineering associations in cooperation with technical societies, universities and industrial organizations should introduce a program of recognizing participation in appropriate continuing education activities by professional engineers, with a view to making adequate participation one element in a review process required for continued professional registration.

41. Engineering faculty administrators should ensure that the incentives experienced by professors are consistent with the primacy of effective education as an objective of their faculties.

42. Universities should recognize that the objectives and responsibilities of professional faculties such as engineering are somewhat different from those of other disciplines.

43. Universities should ensure that their recruitment and advancement criteria for professors are sufficiently broad to include the special needs of engineering faculties. These criteria should include appropriate recognition of teaching performance, research, development and design contributions, professional experience and accomplishments, service to the community, and contributions to the planning, management and administration of the educational process.

44. The National Council of Deans of Engineering and Applied Science (NCDEAS) should develop an appropriate set of criteria for initial recruitment of engineering faculty, for the achievement of academic tenure and for promotion to full professorship.

45. In the application of advancement criteria for engineering professors, universities should give significant weight to input from persons who have a good understanding of the nature and needs of the graduates and the profession: practising professional engineers, recent and mid-career engineering graduates and senior professorial colleagues with appropriate engineering experience.

46. Engineering faculty administrators should ensure that newly appointed professors have adequate opportunity and incentive to plan a relevant research program and to establish good contacts in industry.

47. Much of the research funding for engineering professors should be based on the potential contribution to issues of national importance to Canada.

48. Agencies such as NSERC, NRC and government departments should establish, expand and emphasize programs supporting cooperative research and development by industry and universities.

49. In evaluating proposals for cooperative research and development involving industry and universities, granting agencies should place emphasis on the willingness of industry to contribute time and funds commensurate with their available resources.

50. Research funding agencies should recognize that the output of greatest value from most academic research is highly educated and trained people.

51. Engineering faculties should ensure that the rewards for good teaching are made as attractive as those of good research.

52. Recognizing the importance of knowledge, skill and broad experience in teaching an introductory course for engineering students, engineering

faculties should make such an assignment a mark of career accomplishment for a professor.

53. Engineering faculties should formulate and gradually establish a policy of recruiting a majority of their professors after some years of effective engineering experience.

54. Granting agencies should expand their industrial postdoctoral fellowship programs.

55. Engineering faculties should provide encouragement and assistance for their professors to spent their sabbatical research and study leaves in industry.

56. Industry should provide appropriate opportunities for the employment of engineering professors during their research and study leaves.

57. Engineering faculties should encourage involvement of their engineering professors in appropriate consulting arrangements with industry and with other users of engineering services.

58. Universities should ensure that the staff-student ratio in engineering faculties is sufficiently large to provide the individual attention which is necessary for adequate professional education.

59. Since much of the activity of engineers is wealth producing, Canadian governments should formulate public education policy to give priority to ensuring an adequate supply of qualified entrants to the engineering profession by providing appropriate targeted resources in support of both engineering education and research.

60. Provincial governments should permit universities to have freedom in setting fee structures for programs such as engineering on the understanding that these funds would be routed to the appropriate faculties. Student loan programs should be provided for those who are qualified but lack the immediate resources.

61. NSERC should accept a broad view of engineering research to include design, development and engineering management. It should continue to support students registered in any of the professional masters programs.