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An Integrated and Comprehensive Approach to Engineering Curricula, Part One: Objectives and General Approach*

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The need for increased professional skill development within engineering programs has been frequently discussed and is widely accepted. There is equal acceptance of the importance of increasing the social and environmental awareness of students of engineering. Efforts to increase these topics within engineering programs are often hampered by the fact that those programs are already heavy and demanding. Integrated Learning is an effort to utilise a broader range of learning techniques, including a conscious use of learning from one's environment, to address these issues in a comprehensive way within the constraints of a four-year program. This paper describes the educational objectives and the general approach. Subsequent papers will deal with issues of techniques, facilities and staffing.

INTRODUCTION

THERE IS ALMOST universal agreement that an effective engineer must possess a broad range of knowledge and skills, extending far beyond the technical expertise of his or her discipline. An engineer must command not only an understanding of theory, but also the skills necessary for the successful elevation of theory to practice: powers of critical analysis, effective communication skills, the ability to perform well in a team, managerial skills, and a capacity for lifelong learning. Engineers who possess all of these traits in abundance are able to apply them not only in engineering, but also in research, in management, and in numerous other fields.

Equipping an engineer with a much broader range of competencies is made difficult by the fact that the specialised material in his or her program is likely to be narrowing. The rapid and exponential growth in knowledge in all engineering fields continues to lead to increased specialisation in the curriculum of engineering programs. The widespread creation of separate computer engineering programs, from what was once a specialisation within a broader electrical engineering program, is one recent and familiar example of this trend. It is a major challenge to satisfy the engineer's growing need to utilise and integrate material from different sources and different disciplines when the engineering content of his or her program is becoming more and more specialised.

These issues, with all their implications, challenges and relationships, have been at the heart of numerous conferences, studies and papers on engineering education. Several of these are quite general [1–13], whereas others focus on specific issues such as design [14], breadth of education and integration of engineering with other disciplines [15–17], sustainability and environment [18], ability to work in multidisciplinary teams [19] and professional skills [20]. Typically, these studies emphasise the importance of engineers possessing the professional skills and the broad cultural awareness required for successful engineering practice. Recent graduates, after a few years of practice, echo these views.

Another influence on engineering education is an increasing interest in using varied teaching approaches in order to improve learning. Educational experts have long maintained that learning in most fields and at all levels is most effective when the student is an active, not a passive, participant in the learning process [1, 6, 21–23]. Learning in a passive system has a much greater tendency to be both superficial and quickly forgotten. Active involvement in learning helps the student to develop the skills of self-learning while at the same time contributing to a deeper, longer lasting knowledge of the theoretical material [23]. While active learning is an important component in teaching purely technical material, because it leads to deeper understanding and better retention, it will be argued in a subsequent paper on techniques that it is almost the only effective way to develop professional skills and to realise the integration of material from difference sources.

TOWARDS INTEGRATED LEARNING

The challenge in responding to these needs is to do so without reducing the quality of the technical

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education and without extending the period of formal education beyond the four years which is standard in Canada. The Faculty of Applied Science at Queen's University is engaged in trying to craft a response which speaks to the needs while respecting the necessity of retaining or enhancing technical quality and the necessity of remaining within a four-year limitation. The program described in this series of papers seeks to make a very significant increase in developing these skills and attitudes on campus, within the confines of a four-year program, and in a systematic way which affects every graduate. We call this initiative *Integrated Learning.*

The components of Integrated Learning are not, in themselves, new. Almost all aspects of professional skills have been addressed to some degree in most engineering schools and any given skill has usually been the subject of imaginative and effective curriculum developments somewhere. What is new is the extent to which all of these skills are addressed and coordinated, in an extensive way which affects every student in every year of every program. There is also an emphasis on interdisciplinarity which is unusual, although not unique, and a conscious use of both structured and unstructured discovery learning. A discussion of these terms will be found below.

Effecting these changes has required not only curriculum innovation, but also the acquisition of some specialised staff, the reorganisation of undergraduate laboratories, and the construction of a new building which provides innumerable opportunities for experiential learning. The background to this development is the subject of this paper. Other aspects of these innovations, including the design of the building, will be discussed in subsequent papers.

ACCREDITATION CONSIDERATIONS

Any major change in curriculum within an educational program subject to professional accreditation must consider the constraints imposed by the accreditation system. In Canada, the Canadian Engineering Accreditation Board requires the inclusion in all programs of many non-technical elements, and Integrated Learning actually strengthens programs from an accreditation viewpoint. In addition to humanity and social science content, the CEAB requires 'studies . . . on the impact of technology on society'. They also require developing 'each student's capability to communicate adequately, both orally and in writing'. The Board further expects 'appropriate exposure to ethics, equity, public and worker safety and health, concepts of sustainable development and environmental stewardship'. Finally, they expect the curriculum to 'prepare students to learn independently'.

In the United States, the American Board of Engineering and Technology has adopted outcome-oriented criteria, known as ABET 2000. These criteria are an ambitious attempt to improve the level of all accredited engineering programs in the USA. Engineering Faculties in the USA are now required to demonstrate that their graduates have the following abilities:

- an ability to apply knowledge of mathematics, science and engineering;
- an ability to design and conduct experiments, as well as analyse and interpret data;
- an ability to design a system, component or process to meet desired needs;
- an ability to function on multi-disciplinary teams;
- an ability to identify, formulate, and solve engineering problems;
- an understanding of professional and ethical responsibility;
- an ability to communicate effectively;
- the broad education necessary to understand the impact of engineering solutions in a global/societal context;
- a recognition of the need for and an ability to engage in life-long learning;
- a knowledge of contemporary issues;
- an ability to use the techniques, skills and modern engineering tools necessary for engineering practice.

In both Canada and the United States, it is clear that many of the topics being emphasised in accreditation criteria are important elements in Integrated Learning. Both CEAB and ABET mandate the need for a range of professional skills and attitudes to complement the technical skills and education. Hence, the changes proposed in Integrated Learning strengthen a program from an accreditation viewpoint.

It is important to note that the bulk of the ABET list is concerned with skills and attitudes, not with content. The criteria are not framed simply in terms of knowledge, but rather emphasise the ability to utilise that knowledge (e.g. 'To identify, formulate and solve', 'an ability to use', 'an ability to function'). The ABET criteria thus implicitly recognise that an education concerned only with knowledge and comprehension, valuable though it is, falls short of what can be achieved through activities at the higher levels of application, analysis, synthesis and judgement. In other words, these criteria address the learning process as well as the learned content.

THE CHOSEN OBJECTIVES

That engineering, mathematics, and science content is essential in any engineering program is obvious. It is a basic assumption of Integrated Learning that the existing curriculum content in engineering, mathematics, science and computing is appropriate and that the existing mechanisms for ensuring the ongoing evolution of that part of the curriculum are, and will continue to be, adequate.

But technical content, of itself, is far from being sufficient if the engineer is to have the skills needed to put theory into practice. These are the skills which Integrated Learning addresses. In addition, Integrated Learning redesigns the undergraduate learning experience to make it more relevant, more effective, more efficient, and more reflective of individual variations in learning styles. The objectives of Integrated Learning are as follows.

Objectives related to professional skills

- *Increase opportunities to improve communication skills:* general writing for a non-specialist audience; technical writing for an expert audience; speaking and verbal reporting to both expert and non-expert audiences; technical discussion with professionals from other disciplines; and the promotion of learning other languages.
- *Increase design content in curriculum:* teaching general principles and approaches to design as well as discipline-specific techniques; encouraging the development of an aesthetic sense; working in multidisciplinary teams on the design of complex systems or equipment; developing open-ended and original approaches to design problems.
- *Develop lifelong learning skills:* promote curiosity; understand the connections among different fields; develop initiative in seeking information; acquire the ability to identify, find and evaluate relevant information; develop self-knowledge and self-confidence.
- *Increase societal understanding and sense of social responsibility:* understanding of how society is organised; awareness of individual, regional and international variability; equity issues; ethical issues.
- *Increase understanding of management and business issues:* introduction to finance and accounting, increased education in project management, opportunities to interact with industry and with government agencies, decision-making weighing economic, environmental, social and technical factors.
- *Increase understanding of environment and sustainability:* general introduction to environmental issues; life cycle analysis and role of environment in design; sustainability in energy sources; development of environmental concern and understanding.
- *Increase awareness of health and safety issues:* introduction to hazards and safety; legal requirements; role of public safety and worker safety in design.
- *Improve team skills:* introduction to personality tests and usage; structure and functioning of a team; experience in teams, including multidisciplinary teams.
- *Broadening knowledge of other disciplines:* knowledge of and understanding of other engineering disciplines; knowledge of and appreciation of other professions.

Teaching and learning objectives

- *Improving student learning:* the provision of a deeper and more lasting understanding of the theoretical material through learning that is active, not passive; increasing interest, motivation and enjoyment; improving retention of theory through immediate application; development of new learning paths; the development of understanding of the application of a particular theory to a range of situations *outside* of one's discipline.
- *Improving program delivery:* monitoring success in learning; developing more and better methods of evaluating success in learning; developing evaluation of continuing education courses; elimination or reduction of arbitrary impediments to learning such as timetable restrictions.
- *Integrate curriculum elements:* link theory more closely to practice; integrate material from different courses (e.g. mathematics with its engineering applications); integrate academic programs with industrial and professional practice; integrate the laboratory activities of different departments in certain subject areas (e.g. the fluid mechanics activities in Chemical, Civil and Mechanical Engineering).

Outreach objectives

- *Outreach to schools:* improving the understanding of the role of technology among elementary and secondary school pupils and teachers; promoting engineering as a career among elementary and secondary school pupils nationally and internationally.
- *Outreach to the public:* broadening the public understanding of technology and its role in society; increasing environmental awareness.
- *Industrial linkages:* arranging industrially based projects; developing continuing education; arranging and evaluating internships; obtaining feedback on effectiveness of programs; showcasing leading technologies; encouraging and facilitating research collaborations.

REALISING INTEGRATED LEARNING

It is common in the analysis of curriculum for someone to ask what division we propose between time spent on technical material and time spent on developing professional skills. The question carries an implication that time added to one must come from the other. We believe that there is no direct connection.

Consider an introductory course in Chemical Engineering Thermodynamics. The content is long established: applications of the first and second law; thermodynamic properties of fluids; steady-state, steady-flow analyses; analysis of devices such as compressors, turbines, valves, throttles and so on. Such a course can be taught purely with lectures. Or it can be taught by a mixture of lectures, laboratories, tutorials and team-based projects. In such a course taught by one author (JDM), a project was introduced which involved teams of students designing a replacement for the university heating plant, each team working with data for slightly different building loads and seasonal weather data. In the course of the project, they became active learners of information on boilers, condensers, turbines and pumps, interested employers of the thermodynamic data in the steam tables, and experienced users of SSSF analyses. But at the same time they learned team skills, communication skills and self-learning skills. The tutorials were altered so that students presented the solutions to the weekly problem sets, and discussed alternatives. The laboratories evolved to make greater use of unknowns. If one looked at the description of this course in the calendar before and after these changes took place, one would see only the technical content, and that would be unchanged. But a great deal of additional education is now involved, *without diminishing the technical content in any way.* Indeed, the understanding of that content is strengthened. And the variety of learning modes accommodates a broader range of learning styles and approaches than does a lecture-only model. And in addition, one can reasonably expect the active learning components to increase the depth of learning [21].

As is illustrated by the example, content can be learned both through lectures and other traditional means and through active learning techniques. The professional skills are learned almost solely through experience in team-based projects, in presenting technical material orally, in seeking information for oneself, and in reflecting on what one has learned and what one needs to learn. The two components, technical content and professional skills, do not compete for time, although a course taught using such a wide variety of means undoubtedly makes more demands on both student and instructor than does a conventional lecture course.

The concept of integrated learning involves much more than choosing learning methods appropriate to the goal. It also involves an educational philosophy and structure that can offer important lessons for an engineer's education. By bringing students from different programs together, sometimes to engage in the same project, but sometimes only to work at the next bench, it broadens the students' understanding of other disciplines without any additional formal instruction. By having a lot of this activity take place in a building which itself exemplifies good practice, another set of learning opportunities is provided. And although examples of the coordinated use of content, program and structure are not common in university education, an understanding of the power of such coordination is not new. In the words of Dewey [24]:

> A primary responsibility of educators is that they not only be aware of the general principle of the shaping of actual experience by the environing conditions, but that they also recognise in the concrete what surroundings are conducive to having experiences that lead to growth. Above all, they should know how to utilise the surroundings, physical and social, that exist so as to extract from them all that they have to contribute to building up experiences that are worthwhile.

Integrated Learning is intended to explore how a conscious integration of content, methods and facilities can be used to educate engineers who not only understand theory, but understand, and have experienced, the complex interactions of that theory with societal needs, economic limitations and environmental imperatives which shape actual practice. By creating a rich range of learning opportunities, by attempting to teach in a context which mirrors professional practice more closely, by bringing students from different programs together for different activities, by constructing facilities to support more varied learning modes and by raising consciousness of surroundings through monitoring building performance, the maximum possible educational value is wrung out of the time available.

Details of the learning techniques adopted and of the reasons for their choice are the subject of a subsequent paper. A third paper will describe the facilities designed to support them.

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