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An Integrated and Comprehensive Approach to Engineering Curricula, Part Two: Techniques*

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In Part I we described the educational objectives that have led to an approach to engineering education which we call Integrated Learning. In addition to improving professional skills and achieving more active learning, the objectives include an increased emphasis on design, an increased understanding of related disciplines, and an increased awareness of, and sensitivity to, societal and environmental factors. This paper deals with choosing learning techniques appropriate to the objectives. A subsequent paper will deal with issues of facilities and staffing.

INTRODUCTION

IN THE PREVIOUS PAPER [1], the objectives of Integrated Learning were described. Important among these are:

- development of communication skills;
- design skills;
- lifelong learning skills and team skills;
- creation of an enhanced awareness of other disciplines;
- sensitivity to social, economic, and environmental factors.

Of equal importance are:

- learning objectives;
- achieving deeper and more lasting understanding of theory;
- integration of curriculum elements.

Finally, there are outreach objectives involving the schools, industry, and the public at large.

In determining what techniques to employ in order to achieve these objectives, we studied examples of successful approaches, both at Queen's and elsewhere. The three universities which have had the most significant effect on our development are:

- Aalborg University in Denmark [2];
- University of Colorado at Boulder in the United States [3];
- Université de Sherbrooke in Canada [4].

Aalborg University uses team-based, project-based learning in all years of all programs, including programs in the humanities and the social sciences. The University, established in 1974, is designed explicitly to support this approach. Every student in every year is part of a team, and that team has a permanent office. The development of team skills, and the utilisation of project-based learning, are exemplary. Aalborg has many novel approaches to both faculty organisation and design of curriculum, and has a substantial staff devoted to improving teaching and to evaluating educational approaches. Links to industry are extremely well developed.

Whereas Aalborg began with a green field and a radical mandate, the University of Colorado at Boulder faced the situation of creating facilities to support new approaches to learning within the context of entrenched departments and an established culture. Change was confined to the engineering Faculty. Our own situation is very much more like that at Colorado than that at Aalborg, and so Colorado has been an especially valuable model for us. Their greatest contribution was the creation of a novel central facility to support all undergraduate engineering programs. It includes several types of learning space which have proven to be effective and versatile. It also utilises building elements in the teaching program, and supports an outreach program to high schools.

The Mechanical Engineering program at the Université de Sherbrooke has made very significant and effective changes in its program. These include the use of design projects extending over more than one year, strong interaction with industry, and incorporation of non-engineers in the design teams. Mechanical Engineering at Sherbrooke has also been innovative and successful in accelerating the development of a professional culture, and in utilising novel assessment techniques to improve learning.

Other innovators in the United States which influenced our development include:

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- Carnegie Mellon University (multidisciplinary approach to product design, interesting use of student projects). Drexel University (integration of course material);
- Massachusetts Institute of Technology (integrated and multidisciplinary approach to design, manufacture and testing in aerospace);
- Ohio State University (handling of design projects in year one);
- Pennsylvania State University (integration of design, manufacture and business considerations in real situations);
- Rensselaer Polytechnic Institute (teaching in 'studios' to achieve immediate integration of lecture and lab material, use of long running projects such as sailplane design and construction, multidisciplinary design laboratory and manufacture);
- Stanford University (learning design through mechanical dissection).

Several Australian schools have introduced new learning methods and innovative approaches. The most influential for us has been the University of Melbourne (team-based learning with each team led by a senior undergraduate, a course on team achievement aimed at researchers in industry and government, and an academic Chair for a senior engineer with a distinguished record of practice but no academic experience).

THE CHOSEN TECHNIQUES

The objectives of Integrated Learning have been described [1] and have been summarised above. The choice of techniques was guided by a determination to remain within the four-year program normal in Canada. Fifth-year solutions are possible, but are not without costs. Addition of a fifth year to a program can be effective, but is costly to both the student and society, and gives the student knowledge but not experience unless other changes are made as well. Off-campus five-year techniques, such as internships or other co-op variants, provide opportunities to develop professional skills through experience, but are uneven in the way in which they develop skills for a particular student, and in how successfully they do so. Internships and other co-op experiences virtually never address the full range of issues included in Integrated Learning. While we support internships, and offer them to our students, they can never address the wide range of issues involved in Integrated Learning.

As a result, the objectives of Integrated Learning are met primarily through changes in the way that many of the courses are presented. By adopting new learning techniques in an extensive and coordinated way, by bringing students from different programs together for different activities, and by constructing appropriate facilities, the objectives can be addressed. The techniques adopted are described below.

Team-based and project-based learning

Team-based and project-based learning are the most well proven methods of developing professional skills and achieving active learning. A student who has a firm grasp of fundamentals, the techniques for team work and communication, the ability to find and assess relevant facts and theory, and experience in employing all three in dealing with a series of projects, will be able to employ these techniques in dealing with any projects in his or her field. The value of problem-based, team-based learning in developing this suite of skills has been the subject of many papers [e.g. 5–7]

Team-based, project-based approaches are ubiquitous in the programs at Aalborg University and are widely used in many engineering schools, including our own. We have made a significant increase in team-based, project-based learning in our current curricula, and there will be a further increase when additional facilities are available. Some current team-based courses predate concepts of Integrated Learning and contributed to its development. Others grew out of it and represent experiment and prototyping of techniques.

An early and very significant development at Queen's was a multidisciplinary, industrially based fourth-year course in Chemical Engineering [6, 8]. This course uses teams from different disciplines, including business and science, to address real problems provided by governmental agencies and industrial companies. The creation of new facilities will allow a considerable further expansion, as well as providing more effective locations for existing team projects. Team approaches are the basis of existing design courses, particularly in Mechanical Engineering.

Team-based, project-based learning has been introduced more recently into our first year program, replacing most of our conventional laboratories [9, 10]. Again, the scope has been limited by existing facilities, but very significant strides have been made. Once new facilities are in place, early in 2004, team-based learning will be introduced even more widely. A significant aspect of this development is the use of senior students as mentors and managers, which provides learning opportunities for the senior students while providing guidance and feedback to the junior students. In time, we intend to develop a formal component of this course in which the senior students obtain training and feedback on their managerial role.

In an undergraduate project, there may not always be enough time for students to acquire the detailed knowledge required for the project unless some direction is given. Such knowledge may be provided by guided exploration of the literature, or even by specialised lectures as is done at Aalborg University, where lectures are of two types, those dealing with the basics (which are subject to assessment) and those providing high-level knowledge in support of a project (which are not assessed directly, only through the projects).

One aspect of team-based, project-based learning where we still have questions to resolve is the matter of assessment. The norm at Queen's University is to assign a numerical grade (0 to 100) to measure performance in any course. In the project courses, our wish is to develop in the students a sense of professional pride, and a desire to learn as much as possible. The best learning may require some chance taking, and we did not want to discourage risk-taking through penalties which might result from noble efforts but failed results. In the first year project course, the first thought was to assign only a pass/fail grade but it soon became apparent that many of the strongest students wanted recognition of superior effort. As a compromise, therefore, we award grades of A, B, C or F in these courses. Such letter grades do not affect a student's overall grade average, and hence do not affect their honours standing, but they do appear on the transcript. Our experience to date has been that students take the projects very seriously, and indeed devote enormous amounts of time to them. We feel that the current system is working, but we are consciously searching for better ways to use assessment methods that reward performance appropriately.

Integrated Learning supports and facilitates team-based, project-based learning outside of the curriculum as well as inside. Teams design and manufacture solar cars, SAE formula cars, various aircraft, various robots, concrete canoes and assorted other vehicles and compete in national and international competitions. These competitions are highly motivating, and the activities provide all of the opportunities for consolidating understanding of theory and for developing professional skills that curricular team activities provide. The Faculty is increasing its support for, and encouragement of, such activities.

Studio and related techniques

Another technique adopted is the use of just-in-time delivery of theory, in which the student is expected to apply the theory immediately to some project, problem or computer exercise. This can be done superbly in the studio type facility developed at Rensselaer. It can be done more cheaply by delivering a significant part of the theory lectures within the 'laboratory' space, with the students applying the theory immediately. Both approaches involve abandoning the normal separation of 'lecture' and 'laboratory', and replacing them with a blended alternative. The 'laboratory' part of such a blended delivery must force the student to understand the theory and apply it in some new context. Both of these variations are part of the Integrated Learning initiative.

A problem which we encountered in pilot experiments with studio approaches has been that they are not easily accommodated to the wide range of student abilities and speeds. Strong students are held back. Weak students find it difficult to keep up. This is one area which will require attention.

Plazas

Many of the laboratory operations from the second and third years of all undergraduate programs will be carried out using sets of instrumented benches in large open areas we call plazas. The plazas can be used by teams or by individuals, and can be used for projects or for existing, non-project based activities. In any of these usages, they offer substantial benefits.

First, they will be open to students at all times, as long as there is sufficient use to justify it. As a result, practical activities are no longer confined to three-hour blocks. Students may resume work in an evening, or on a weekend. This removes the artificial constraint of a two- or three-hour laboratory slot, allowing longer, more realistic and more complex activities, allowing different students to move at different paces, and allowing students to repeat or vary measurements if they wish.

Secondly, by functioning throughout the day and on weekends, they provide for more intensive use of space and equipment, with potential savings in costs.

Finally, each student functions in an environment in which other students are carrying out quite different activities all around them. There are repeated opportunities for a student to observe something of the interests and activities of students in other engineering disciplines. This is a very small example of experiential learning, a technique which is exploited extensively in Integrated Learning, sometimes in innovative ways.

To develop experience and help shape the final design of the plazas, a small prototype plaza has been built and used in both a second-year mechanical engineering course and in a fourth-year chemical engineering course. A second-year electrical laboratory has been repeatedly modified to experiment with studio techniques within a plaza type setting.

Experiential learning

The fact that human beings are constantly learning from experience is obvious. At some stage of human history, presumably, all learning came from experience, and a substantial portion of it continues to do so. Integrated Learning seeks to make use of experiential learning within the context of formal curriculum, and outside of it.

Dewey discusses, in a comprehensive way, the relationship between experience and formal education. Dewey's concerns are mainly with elementary and secondary school students but many of his thoughts are relevant to education at any level. Dewey makes the point [11] that experience shapes people, the city child differently from the rural child, the slum child differently from the privileged child.

> Ordinarily, we take such facts for granted as too commonplace to record. But when their educational import is recognised, they indicate a second way in which the educator can direct the experience of the young without engaging in imposition. 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.

Despite Dewey's influence on progressive education in the school systems, particularly in the United States, it was not until two decades ago that there was significant examination of the place of experiential learning in formal education at the university level. Kolb [12] analyses the most significant contributors to the development of experiential learning, particularly Dewey, Lewin and Piaget. He explores the significant commonalities in their interests and their approaches, as well as the very significant differences. In particular, he develops and examines models of the learning process and explains the role of, and necessity for, observation, reflection, abstract conceptualisation and experimentation in experiential learning.

It is important to note the range of activities that fall within experiential learning. At one extreme are situations that have been constructed by the instructor, are experienced by every student, and are subject to assessment. Such well established techniques as problem sets and laboratory exercises fall into this class. Close to the other extreme are situations that arise out of real life, are uncontrolled by the instructor, and are open-ended in their solution. They are, however, still part of the curriculum and are subject to assessment. The industrial projects described earlier [6, 8] are examples. A step beyond these would be competitive team activities, such as the solar car team or the cargo aircraft team. These are not part of the curriculum, are not experienced by everyone, and are not necessarily subject to assessment.

Beyond even this, however, is education delivered largely or entirely by creating instructive experiences, and seeking to encourage students to be aware of, and reflect on, those experiences. The environment is there to support learning, to promote reflection, and to create the interest and the motivation necessary for the student to utilise the opportunities, but there may be little faculty participation. Engineering students are typically interested and motivated, but the educator still has a crucial responsibility to foster interest and curiosity. While such an approach may not even qualify in some people's minds as education, it is in fact a large part of university learning for those with curious and active minds. Through just such opportunities, an engineering student can participate in choral music, or learn to fence, or join a debating team. Learning opportunities in engineering can be offered in exactly the same way.

Integrated Learning employs structured experiential learning in a very extensive way, particularly through project-based learning. In this, it is not unusual. It *is* probably unusual, however, in the extent to which it consciously tries to utilise unstructured experiential learning. Our intention is to design a building and develop a culture in which the students learn from the environment created by the building in which they work and study. This is directed particularly toward developing an appreciation of sustainability and environmental technology, and of health and safety practices. While the design of the building will be the subject of a subsequent paper, it is appropriate to note here that the building will meet high environmental standards, and the culture of the building will involve exemplary practices. Data on the performance of building technology will be available to every student, and indeed to the world, on a continuous basis, including the performance of sustainable energy sources both on and off campus.

While learning from structured and directed experience (as in team-based projects) is fairly widely understood and accepted in university programs, learning by unstructured and partially serendipitous experience is not. Learning by conscious and unconscious observation of one's surroundings is in fact the way that much human learning, from infancy on, occurs. It is the way one learns during an internship, and the way in which one learns much of what one learns throughout life. Despite this, such learning has not often played a conscious role in university programs. Nevertheless, it has great potential, particularly in regard to behavioural, environmental, and sustainability issues. Ehrenfeld *et al.* [13] noted:

> Key to the creation of critical thinking and the development of sustainability norms is the experience of living (and learning). Opportunities for learning simply by being in the university setting have been largely overlooked in traditional pedagogical models. The wholeness of the student's social life and learning experience are generally divided into two separate domains. By merging the two, in the context of sustainability, the university can provide a place where students can learn simply by being there.

Integrated Learning attempts to create an environment from which students learn through repeated exposure to technologies and procedures. Throughout their time in the Faculty, the students will work in the Integrated Learning Centre and observe its operations. Many building functions will be monitored and the data displayed. All of the building's engineering functions can be observed in relation to interactions with the natural environment and the human needs. Data may be related to a structure with which the student is completely familiar. Recycling procedures, safety practices, air quality, team structures and the like will all communicate to every student that these are important issues which the best engineers treat as important.

It might be noted in passing that this kind of unstructured learning from the environment takes place whether we allow for it or not. If we lecture the students on the importance of sustainability, but allow constraints of time or money to excuse not making sustainability a priority in practice, the students learn *that* lesson. They learn that sustainability is an attractive concept, but one that is quickly abandoned, if it is thought of at all, in planning a building where funding or timing are pressing. The Integrated Learning Centre teaches a different lesson, and it is hoped that all future engineering buildings at Queen's University will demonstrate that we 'practise what we preach'.

The desire to create an environment from which the student can learn (in both structured and unstructured ways) was one of the major reasons for creating a new building, and a dominant factor in its design. Details of that building, what it contains, and what it attempts to do, will be provided in a subsequent paper.

THE COMPATIBILITY OF EXPERIENTIAL LEARNING AND RECEPTION LEARNING

In the specific context of undergraduate engineering programs, Foster [14] discussed the role of *reception learning* and one of its subdivisions, *expository learning*, relative to *discovery learning* or *experiential learning.* Reception learning encompasses lectures, seminars, tutorials and textbooks in which the lecturer selects and organises material, and presents them in a way thought to facilitate their assimilation by the student. In discovery learning, the instructor creates situations in which the student discovers facts and concepts in a less structured way. The student must organise these discoveries on his or her own in order to build understanding. Laboratory classes and problem sets are common examples of discovery learning in engineering programs.

Foster makes a strong case for the need for effective expository learning in engineering programs, based on cost, on efficiency and on effectiveness. He raises concerns about what he sees as a current fashionability of discovery learning. However he does so purely in the context of teaching engineering principles and their applications. Even within this context, he recognises the value of discovery learning with regard, for example, to understanding 'experimental error, incongruities between the predictions of idealised mathematical-physical models and the behaviour of the corresponding equipment, and the making of a mental model of a plant before operating a valve or starting a pump'.

Integrated Learning accepts Foster's arguments regarding the efficiency and effectiveness of reception learning in building the central core of engineering knowledge. It also accepts, and builds on, Foster's acceptance of discovery learning where one is developing the student's ability to elevate theory to practice. In learning how to put theory into practice, experiential learning is both effective and efficient. And the extension to practice, of course, extends far beyond Foster's focus on engineering principles. It also includes team skills, environmental awareness, societal awareness and so on.

Experiential learning also supports integration of material and a holistic approach. There has been an explosion of awareness that meeting environmental and societal needs requires a great change in how corporations, governments and other organisations, including universities, carry out their operation. There must be ways to introduce far more factors into decision-making than exist at present [15]. While Integrated Learning makes only a small contribution to such concepts, it is very much in accord with them, and its team-based projects are central to integrating concepts from different areas, and to connecting theory to application.

The literature on experiential learning, both in support and in opposition, often implies that a choice must be made between experiential learning and reception learning. I cannot emphasise too strongly that Integrated Learning does *not* select experiential learning over expository or other forms of reception learning. It utilises both and seeks to apply each in appropriate ways. Lectures, textbooks, and web-based information remain concise, efficient methods of transmitting the information which engineers must have in order to practice. They are also effective ways of explaining theories and of pointing out many important relationships. Experiential learning in its many forms project-based learning, problem-based learning, case studies, laboratories, internships can develop student interest and motivation, connect theory to practice, and develop a host of professional skills from communications to life-long learning. It leads to higher cognitive outcomes concerned with analysis, synthesis and evaluation. And it serves to illuminate the theory, to connect theory to other theory and to practice, and to provide a deeper and more lasting understanding of the theory. The two forms of learning are complementary. We are in complete agreement with Chickering [16], who states in his discussion of experiential learning and reception learning:

> Our concern therefore is not confined to such events as encounter groups, field observations, travel or work. Nor does it reject the value of lectures, print, films, videotapes, and audiotapes, or other forms of mediated instruction or vicarious experience. There is no progress to be made by substituting one totality for another. The problem is to create that combination that is most effective for the person doing the learning and for the material to be learned.

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