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The Integrated Learning Centre at Queen's University in Kingston: a new facility for engineering education

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ABSTRACT: The Faculty of Applied Science at Queen's University in Kingston, Canada, has created a new initiative in curriculum known as Integrated Learning (IL). This approach to engineering education has five major objectives, including an increase in the proportion of active learning (rather than passive learning) in all programmes, an increase in the learning of professional skills (self-learning skills, team skills and communications) and attitudes (social, environmental and economic) in conjunction with relevant technical work, an increase in the knowledge that each engineer has of other engineering disciplines, an increase in the quality and extent of design education, particularly interdisciplinary design, and to provide a *home* for first year students, who have not yet chosen an engineering disciplinary and have, until now, lacked a space of their own. An effective workspace for students has proven to be a limiting factor in the implementation of innovative curriculum. In this article, the authors discuss the Queen's Integrated Learning responses to those spatial needs and reflects this against another concurrently developed education initiative, namely the *Conceive – Design – Implement – Operate* (CDIO) Initiative.

INTRODUCTION

The Faculty of Applied Science at Queen's University in Kingston, Canada, is modifying the content and delivery of its programmes through a new curriculum initiative known as Integrated Learning (IL). Similarly, Chalmers University, Linköping University, the Royal Institute of Technology (KTH) in Sweden and the Massachusetts Institute of Technology (MIT) in the USA, have together launched an engineering education initiative based on the context of *Conceive – Design – Implement – Operate* (CDIO) [1]. While IL and CDIO were developed separately and have some significant differences in emphasis, they also have much in common and the learning spaces designed and constructed for IL have the potential to be useful models for new construction in schools pursuing CDIO. In this article, the authors explore those possibilities.

The Faculty of Applied Science at Queen's offers 10 four-year programmes in engineering. The first year class of approximately 600 students takes a common curriculum in year one, and does not select from among the 10 programmes until the end of that year. The quality of students entering Queen's is very high and failure rates are correspondingly low. The Faculty has about 2,600 students in the four years, about 90% of whom live in residence or in rented accommodation located within walking distance of the University.

More than a decade ago, when the Faculty began the process that led to IL, all of these were factors in determining this approach. Moreover, there was a need to meet certain objectives within the context of a university with conventional buildings, established procedures, inflexible interfaculty linkages, highly independent academic units and staff who had been schooled in an expository teaching style. This had to be undertaken at an affordable cost and within a four-year degree programme. The challenge was significant.

IL is the response of Queen's University to this challenge. It seeks to develop professional skills and to achieve deeper learning through an increased emphasis on how technical material relates to other ideas and subjects. It links material in one course to materials in other courses, links material in one engineering discipline to approaches and materials in other engineering disciplines, and links engineering to business, environmental and social contexts. It emphasises how to elevate theory to practice. It also tries to utilise everything from the structure of the building to the operation of its facilities to achieve these aims.

THE OBJECTIVES OF INTEGRATED LEARNING

The following five major objectives emerged in the planning:

- Increase the proportion of learning that is active, rather than passive. The adoption of team-based, project-based learning in year one, the widespread use of such learning in year four and the growing use of team-based learning in the intermediate years created a need for new kinds of space;
- Increase the learning of professional skills (self-learning, teaming and communication) and attitudes (social, environmental and economic) in conjunction with technical work. Project-based learning is a major learning tool for such topics;
- Increase the knowledge each engineer has of other engineering disciplines and other professions in general. This led to the creation of plazas (described below), where different years and different programmes can function simultaneously. It also led to the creation of an area for competitive teams where teams can readily collaborate;
- Increase the quality and extent of design education, particularly interdisciplinary design. This led to the establishment of the design studio and the prototyping centre, plus the establishment of a chair in design engineering;

- Provide a *home* for students in the common first year. The new structure provides first year studios for projects, group rooms for team meetings and an office for the Director of First Year Studies.

More detail on these objectives and on the techniques chosen to realise them can be found in two previous papers [2][3].

The Faculty had very little space suited to supporting such objectives, and thus began the process of designing and building Beamish-Munro Hall to house the *Integrated Learning Centre* (ILC). Three guiding principles were adopted.

The Guiding Principles in Designing the Building

First, the building must be attractive to students. Students were consulted via various means, and the architects gave great attention to making the building attractive and exciting for students, a place where they would feel ownership and want to spend time. The Engineering Society has its offices just inside the main door and the building is open long hours, seven days a week. There is a student-managed café on the ground floor, as well as a student lounge on the second floor. Both of these will support evening and weekend use, and contribute to the liveliness of the building.

Secondly, the building and its equipment and operations must provide as many learning opportunities as possible. In many cases, this simply involves exposing features that would normally be concealed. In others, it involves monitoring the building's operating systems and putting the data online for use in classes, projects or for personal interest. This is called the *live building* approach. Experiential learning was discussed in a previous paper [3]. The *live building* provides a method to magnify one's opportunities for such learning, as well as provide data that can be incorporated into lecture courses and projects.

Thirdly, since students learn outside the classroom, as well as inside, it is important that the lessons learned there set high standards. Therefore, a particular effort was made to create a building conforming to the highest standards of environmental concern. The Building Research Establishment Environmental Assessment Method (BREEAM) approach was adopted and every effort was made to include green features which were not only good practice in themselves, but also served to introduce students to these technologies. In addition, the health and safety standards are high. This is called the *green building* approach.

WORKSPACES IN THE ILC AND THEIR RELEVANCE TO CDIO

Although conceived and developed independently, the IL initiative at Queen's and the CDIO Initiative at Chalmers, the KTH, LiU and MIT have much in common. Both strengthen the *conceive* and *design* components of the curriculum, and the IL emphasis on team skills, self-learning skills and communication skills, as well as social, environmental and economic constraints, which speak to many of the key issues in *implement* and *operate*.

In both programmes, it has been apparent that existing university facilities can be limiting factors in the implementation of innovative curriculum. Different kinds of workspaces are required to conceive ideas, design products and systems, implement hardware and/or software solutions, and operate to test and validate. These are issues addressed in CDIO by, for example, the development of the Learning Laboratory for Complex Systems at the MIT.

At Queen's, it was recognised early in the development of IL that existing University facilities would limit the implementation of such innovative teaching methods. Therefore, based on the IL objectives and the guiding principals for designing the building, a new, purpose-built facility named Beamish-Munro Hall was constructed to house the ILC. The new building creates shared space, as well as accommodating all of the key engineering administrative bodies. Engineering student government (the Engineering Society), Faculty of Applied Science administration and the ILC support staff, as well as the offices of two Faculty-wide Chairs are all resident in the ILC. As a result of this centralisation, and in combination with a wide variety of curricular and extra-curricular student activities in the ILC, engineering students from all disciplines and all years of study regularly use the building, encouraging multidisciplinary and multi-year interaction. Descriptions of the various facilities within the ILC are provided in Table 1.

Table 1: The description of ILC facilities.

Group rooms	42 group rooms are fully dedicated to undergraduate students. Designed for simplicity and flexibility, these rooms are available to all undergraduate engineering students to meet for team discussions in a quiet and private setting. Group rooms are *booked* online or at a kiosk in the ILC atrium for up three hours in one hour blocks, and up to three days in advance. There are two nominal sizes of group room. The large rooms, of which there are 14, comfortably seat 12 people. The remaining 28 rooms seat approximately six people. All group rooms are equipped with a boardroom table, chairs, a large whiteboard, and have AC power and Intranet connections throughout the room. The group rooms, like the rest of the ILC, also accommodate wireless Internet connectivity. These rooms are designed to support the large number of student team activities throughout all years of the undergraduate engineering programmes. Teams meet to review and discuss problems, *conceive* ideas, *design* solutions, products or systems, write reports, prepare presentations, or assemble and test prototypes (*implement*).
Active Learning Centre (ALC)	A large, flexible classroom, the Active Learning Centre (ALC) holds up to 100 people. Equipped with relatively small tables and light, mobile chairs, the room can be quickly configured in any desired arrangement and is subdividable. With whiteboard and project capability at both ends of the room, the ALC is a versatile space that can be used for teaching, presentations, meetings or even constructing and testing parts and assemblies. Lockable cupboards in one wall offer storage for a variety of laboratory materials, tools, etc. Additional external storage space accommodates custom-built trolleys for supplementary equipment that cannot be stored in the in-room cupboards. In CDIO terms, this workspace is suitable for *conceiving*, *designing* and, to some extent, *implementing* engineering solutions.

Active Learning Centre (ALC)	The first two years of operation demonstrated the tremendous flexibility of this room with a combination of scheduled classes, large student group meetings, seminars with faculty, students and industry, and a wide variety of other less obvious activities, such as rehearsal space for student/faculty musical groups. Several interactive design courses have adopted this facility, and the feedback from both instructors and students has been very positive. In conjunction with the ALC, students extensively used the ILC's group rooms for *conceiving* and discussing ideas, the *prototyping centre* (described below) for constructing their designs and competitively tested them in an organised event held in the ILC *atrium*.
Teaching studio	The teaching studio is an extension of developments at Rensselaer Polytechnic Institute [4]. It accommodates up to 76 students seated in two concentric rows in an elliptical room. This arrangement allows students to switch back and forth readily between lecture mode and application mode. While facing inward, students view a monitor upon which the instructor can explain material by projecting images from a computer, the Web, an electronic *blackboard* or a video camera. Turning to face outward, students have access to computers and other relevant equipment that can be used to *conceive* and *design* (with CAD or other design related software), build (such as breadboard circuits), *implement* (digitally with software or physically with equipment) and analyse. In doing so, students must immediately apply the theory presented in the lecture material. The ability to shift back and forth between lecture and application modes allows the instructor to apply each teaching mode in order to ensure that students can understand and apply engineering theory, software tools or other instructional elements.
First year studios	The ILC includes two *first year studios* that are designed to support the project content of the common first year. Modelled somewhat upon similar facilities at the University of Colorado at Boulder, USA, each studio is designed to accommodate about 36 students. All first year engineering students at Queen's participate in a course entitled *Practical Engineering Modules*, which includes a term-length team design project. To support these projects, each studio is equipped with a variety of tables, chairs, benches, stools, hand tools, small power tools, whiteboards, projection equipment and a few computers. In addition, storage lockers are built into the walls within the studios and in the hallways outside to accommodate the physical elements of student projects in a convenient location. Student teams use these studios for the duration of the term length project, incorporating *conceive*, *design*, *implement* and, in some cases, *operate* phases of the project.
Plazas	Included in the ILC are *plazas* equipped with instrumented workbenches suitable for teams of up to four students. All benches are equipped with computers, and some have additional equipment such as function generators and oscilloscopes. The plazas are used by a variety of courses and, depending on the need, additional equipment is moved from storage areas to the benches as required. For teaching requirements, information can be transmitted from the instructor's station to all bench-top monitors. In this manner, similar to the teaching studio, the learning mode can change from application to instruction and back quickly and efficiently. Students may utilise software on the plaza's computers for *design* and analysis and, in conjunction with mobile equipment, can *implement*, *operate* and test devices and systems. The plazas are available to students in the evening and on weekends in order to provide addition time to complete laboratories, projects or for general study.
Design studio	A *design studio*, which is arranged in a manner common in industry practice, is housed within the ILC. Open to all disciplines and years of engineering students, the studio is equipped with powerful computer workstations loaded with a wide variety of design and analysis software. Each station is located at a table large enough for 4-6 students. As a unique feature, most workstations and monitors are mounted on the wall, allowing the tables (which have casters on one end) to be moved around to accommodate larger group meetings, seminars or other activities. An instructor's station, large whiteboard and extensive audio/video equipment are included to accommodate design instruction. The use of the design studio has grown steadily, both for design teaching and student project activity. It is commonly used on evenings and weekends both by teams and individuals. As intended, the typical student cross section in the evening or weekend hours is both multidisciplinary and multi-year. The group table arrangement accommodates team discussion and idea generation (*conceiving*), while the workstations support extensive *design* and analysis.
Prototyping centre	Readily available to all engineering students, and directly across the hall from the design studio, is the *prototyping centre*. The prototyping centre is split so that approximately two-thirds of the space incorporates a small machine shop and fabrication area, while the other third houses modern *rapid prototyping* equipment, such as a *3D printer*, circuit board router and laser sheet cutter. The fabrication area is arranged with a large bench area, stools to accommodate up to 16 students, and power and compressed air supplies. Following safety training, hand and small power tools are made available to students, and those who wish to do so can also train to use the larger equipment such as the mill and lathe. The prototyping centre is extremely busy, accommodating project activity from all years of the curriculum in supporting the *implementation* and, to a lesser extent, the *design* and *operation* of product and system prototypes.
Competitive team area	Many Queen's students are actively involved in extracurricular student-managed projects involving competition with similar teams at other universities. Prior to the completion of the ILC, these projects were scattered across (and beyond) the campus due to limited space availability. The ILC has responded to this issue with five *garage* style spaces, each with an associated office and lockable garage doors. All open onto a large common *team assembly area* with an overhead crane and level access to the street via a large garage door to accommodate passage of both supplies and the *products*. With the combined office and manufacturing workspace, this facility supports all aspects – *conceiving*, *designing*, *implementing and operating* – of student-managed multidisciplinary projects. Examples of project teams housed in the ILC include the solar car, concrete canoe, aero design, concrete toboggan, fuel cell, glider and an autonomous robot. Not only is this dedicated new workspace comfortable and convenient for the student managed teams, but the common locale and the additional shared workspace encourage communication, synergy and support for all. The feedback on this space has been very positive.

Multimedia studio	Seating up to 20 people, the multimedia studio provides a private area where students can develop and practice presentation skills. An array of audio-visual equipment is provided to allow students to record and review their performance. The rear wall of the room can be retracted to accommodate a larger audience. This room is provided for the benefit of students who wish to develop these skills. It is not used for instruction of any course. However, it is frequently used for the preparation and delivery of formal presentations for courses and projects. The multimedia studio supports and encourages the *implementation* of practical presentation skills necessary for effective communication.
Site Investigation Facility	A site investigation facility allows samples obtained in fieldwork to be processed, analysed and stored. It is of interest primarily to those students enrolled in the geological, mining and civil engineering disciplines. Typically very *hands-on* activities, the site investigation facility provides students with the opportunity to *implement* techniques and *operate* equipment consistent with professional engineering practice in related fields of study. For example, this facility has supported first year team projects in viewing and analysing samples obtained from an environmentally sensitive marsh near the city centre.
Live building	The building's structure and functions contribute to the learning programme wherever possible. This can be as simple as exposing structural elements not normally exposed and providing explanations on the Web or through signage. Of even greater interest is data collected on building parameters. The operation of all large buildings requires the monitoring of certain building parameters in order to operate the HVAC system, the power system and so on. Some recent buildings monitor performance beyond operational requirements, purely for educational purposes. The ITLL at the University of Colorado at Boulder uses the *Building as a Learning Tool* [5]. The ILC incorporates an extensive system of sensors to monitor structural, electrical and mechanical elements to provide data for educational and research activities. Monitored systems include a large photovoltaic (PV) array, building power consumption (24 meters), the building envelope (outer wall), elements of the HVAC system including the *enthalpy wheel*, lights (on/off and brightness levels), *green wall* (three-storey internal wall with living vegetation), solar heat gain on glass, room temperatures, steam and water lines, and a structural column. Many of the data from these instrumented systems is now available on the ILC Web site, providing opportunities for any students and researchers with Internet access. In addition, the Queen's Physical Plant Services (PPS) are using energy consumption data for energy reduction studies and, in turn, have provided online access to an additional 90 power meters utilised across campus. Already a wide variety of student projects from various disciplines and years have used *live building* data from the ILC. Operational data such as this are a critical element to help students understand the *implementation* and *operation* of systems in a real-world application. It would be reasonable to assume that this information will ultimately lead to the *conception* and *design* of new and more efficient buildings, as well as energy use systems.

The variety of facilities in the ILC accommodate the full range of *conceive*, *design*, *implement* and *operate* elements. Table 2 describes the relationship between ILC facilities and CDIO elements.

Table 2: The relationship between ILC facilities and CDIO elements.

	Conceive	Design	Implement	Operate
Group rooms	✓✓✓	✓✓	✓	
Active learning centre	✓✓	✓✓	✓	
Teaching studio	✓	✓	✓	
First year studios	✓✓	✓✓	✓✓	
Plazas		✓	✓✓	✓✓
Design studio	✓✓	✓✓✓		
Prototyping centre		✓	✓✓✓	✓
Team assembly area	✓	✓	✓✓✓	✓✓
Multimedia studio			✓✓	✓
Site investi-gation facility			✓✓	✓✓
Live building	✓	✓	✓✓	✓✓

NB: The number of checkmarks indicates the strength of the relationship.

CONCLUSION

In looking back on the first two years of operation, it is clear that there has been much progress and all of the objectives have been at least partially achieved. Feedback from students and instructors in using the ILC has generally been positive. Most facilities are well used and demand is growing.

Industry and public awareness, as well as involvement in engineering, have been improved. The ILC has already hosted several engineering class project displays to industrial representatives, industry/academic partnering fora, an *Art and Engineering* display, and dramatic plays open to the public.

The building itself has received international attention. Recognised for its *green* characteristics, the ILC has earned *four leaf* status in a BREEAM evaluation (it should be noted that BREEAM is somewhat more extensive than the better known LEED and is being introduced more broadly to the world as *Green Globe*) [6]. In addition, Beamish-Munro Hall was selected to represent Canada in the institutional and commercial building class at the *2005 World Sustainable Building Conference* in Tokyo.

Students and instructors are evolving methods to optimise the use of the facilities. For example, motivated by the positive experience of teaching in the new teaching studio, one instructor organised a well attended series of discussions and an instructional seminar open to all faculty to discuss best practice for teaching methods in this new facility.

Not surprisingly, some aspects IL and the ILC have not evolved at the pace or to the degree initially hoped for. Creating a building with exemplary environmental standards has been challenging and the success, while considerable, is far from total. Obstacles lay in long-held opinions and established practices among administrators, architects, engineering consultants and colleagues. Interestingly, this very problem relates to the reasons for incorporating green technology in the building.

It is believed that the reluctance of engineers to incorporate green technology often stems from unfamiliarity. Given that engineers bear the ultimate responsibility for performance, it is not surprising that they so often adopt familiar and well proven technologies. By incorporating many green technologies in the ILC so that the student sees them and can monitor their performance over several years, it is hoped that the barrier of unfamiliarity will be overcome and the education of engineers, who are confident of the reliability and aware of the limitations of such technologies, is fostered.

Anyone interested in adopting some portion of this approach in support of CDIO objectives is welcome to whatever help can be provided. Further information on the Queen's ILC in Beamish-Munro Hall can be accessed at http://appsci.queensu.ca/ilc/ or else the authors can be contacted. Additional ILC contacts are available (http://appsci.queensu.ca/ilc/contacts/team.php)

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