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EFFECTIVE WORKSPACE FOR ENGINEERING EDUCATION: The Integrated Learning Centre at Queen's University in Kingston

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ABSTRACT

The Faculty of Applied Science at Queen's University in Kingston is developing 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 programs; an increase in the learning of professional skills (self-learning skills, team skills, communications) and attitudes (social, environmental, economic) in conjunction with relevant technical work; an increase in the knowledge which each engineer has of other engineering disciplines; and an increase in the quality and extent of design education, particularly interdisciplinary design. The fifth objective is to provide a "home" for first year students, who are not yet associated with any particular program, and have until now lacked a space of their own.

Although conceived and developed independently, the IL initiative at Queen's and the CDIO initiative developed by Chalmers, KTH, LiU and MIT have much in common. In both programs, it has been apparent that existing university facilities can be limiting factors in the implementation of innovative curriculum. This paper discusses IL responses to those spatial needs.

Index Terms – Integrated Learning, CDIO, engineering education, workspace, professional skills.

INTRODUCTION

The Faculty of Applied Science at Queen's University in Kingston is modifying the content and delivery of its programs through a new curriculum initiative known as Integrated Learning. Similarly, Chalmers University, Linköping University, the Royal Institute of Technology (KTH), and the Massachusetts Institute of Technology (MIT) have together launched an engineering education initiative based on the context of Conceiving-Designing-Implementing-Operating (CDIO) [1]. While Integrated Learning 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 Integrated Learning have the potential to be useful models for new construction in schools pursuing CDIO. This paper explores those possibilities.

The variations among engineering schools are many and large, and what is ideal for one will require modification in another. It is therefore necessary to be aware of those parameters at

Queen's which influenced our choices in developing Integrated Learning.

The Faculty of Applied Science offers ten four-year programs in engineering, six of which are classical programs (Chemical, Civil, Computing, Electrical, Mechanical and Mining) and four of which are engineering science programs (Engineering Chemistry, Engineering Physics, Geological Engineering and Mathematics and Engineering). The first year class of approximately 600 students takes a common curriculum in year one, and does not select from among the ten programs 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 2600 students in the four years.

Queen's is a residential university, and over 90% of its students are in residence or in rented accommodation located within walking distance of the University. There is a long tradition of being on campus evenings and weekends, both for learning and for social activities.

More than a decade ago, when the Faculty began the process which lead to Integrated Learning,, all of these were factors in determining our eventual approach. Moreover, there was a need to meet our 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. We had to do so at an affordable cost and without extending the time taken to obtain a degree. The challenge was significant.

Integrated Learning is the response of Queen's University to the challenge above. 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 material in other engineering disciplines, and links engineering to business, environmental and social contexts. It emphasizes how to elevate theory to practice. And it tries to utilize everything from the structure of the building to the operation of its facilities to achieve these aims.

THE OBJECTIVES OF INTEGRATED LEARNING

Five major objectives emerged in our planning. More detail on these objectives, and on the techniques chosen to realize them, may be found in two previous papers [2,3].

(a) We wished to increase the proportion of learning which is active, rather than passive learning. 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. The group rooms and the first year studios are direct responses to this need. So is the site investigation facility. In addition, the teaching studio and the active learning centre create opportunities to experiment with other active methods.

(b) We wished to increase the learning of professional skills (self-learning skills, team skills, communications) and attitudes (social, environmental, economic) in conjunction with relevant technical work. Project-based learning is a major learning tool for such topics.

(c) We wished to increase the knowledge each engineer has of other engineering disciplines and, indeed, of other disciplines generally. This led to the creation of the plazas (described in a later section), where different years and different programs can function simultaneously. It also led to the creation of an area for competitive teams, where the teams can readily collaborate.

(d) We wished to increase the quality and extent of design education, particularly interdisciplinary design. This led to the establishment of the design studio and the prototyping centre, and to the establishment of a chair in Design Engineering.

(e) We wished to provide a "home" for first year students. As noted above, students take a common first-year program and do not choose a discipline until the end of year one. In the upper years, the host department for each program provides advisors, a lounge and general office support for each student, but such facilities have been lacking for year one students. The new structure provides first year studios for projects, group rooms for team meetings, and a home for the Director of First Year Studies.

The Faculty had very little space suited to supporting such objectives, and it was necessary to create some. Thus began the process of designing and building Beamish-Munro Hall, to house the Integrated Learning Centre (ILC). Once the decision to create such a structure had been taken, the Faculty looked for ways to obtain the maximum educational value from the new building. Three guiding principles were adopted.

The Guiding Principles in Designing the Building

First, the building must be attractive to students. Students were consulted in many ways, 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. If and when university approval is finally obtained, there will be a café/lounge 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. The café will be student operated, and will provide opportunities for learning business and communication skills, and for introducing environmentally responsible methods.

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 on line for use in classes, in projects, or for personal interest. This allows students to see how building operation changes in response to occupancy, time of day, time of year, weather and so on. We call this the "live building" approach. Experiential learning was discussed in a previous paper [3]. The "live building" provides a way of magnifying one's opportunities for such learning, as well as providing data which can be incorporated into lecture courses and into projects.

Thirdly, since we all learn outside of 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 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. We call this the "green building" approach.

WORK SPACES IN THE INTEGRATED LEARNING CENTRE AND THEIR RELEVANCE TO CDIO

Although conceived and developed independently, the Integrated Learning initiative at Queen's and the CDIO initiative at Chalmers, 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 speaks to many of the key issues in "implement and operate".

In both programs, it has been apparent that existing university facilities can be limiting factors in the implementation of innovative curriculum. Different kinds of workspaces are required for conceiving ideas, designing products and systems, implementing hardware and/or software solutions, and operating to test and validate. These are issues addressed in CDIO by, for example, the development of the

Learning Laboratory for Complex Systems at MIT.

At Queen's, it was recognized early in the development of Integrated Learning that existing university facilities would limit the implementation of such innovative teaching methods. Therefore, based on the Integrated Learning objectives and the guiding principals for designing the building, a new, purpose-built facility named Beamish-Munro Hall was constructed to house the Integrated Learning Centre (ILC).

Engineering departments at Queen's University have been, and still are, housed in separate buildings on the Queen's main campus. There was no engineering facility common to all disciplines. 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 and the offices of two Faculty-wide Chairs are all resident in the ILC. As a result of this centralization, 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.

The variety of facilities in the ILC accommodate the full range of conceive, design, implement, and operate elements. The following table provides an overview of these facilities and their CDIO relevance.

	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 Investigation Facility			✓✓	✓✓
Live Building	✓	✓	✓✓	✓✓

(Number of checkmarks indicates the strength of the relationship)

Figure 1: Relationship Between Integrated Learning Centre Facilities and CDIO Elements

Group Rooms

Forty-two 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" on-line 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, will comfortably seat twelve people. The remaining 28 rooms will seat approximately 6 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 programs. Teams meet to review and discuss problems, *conceive* ideas, *design* solutions, products, or systems, write reports, prepare presentations, or assemble and test prototypes (*implement*). With the potential for hundreds of student teams in every year of study, it is not surprising that the rooms were well used in the ILC's first year of operation after the start-up phase. Based on usage in the winter term (January to April), it is estimated that rooms were used at about 75% capacity in the evenings, except in the last few weeks of term when after classes the rooms were booked to full capacity.

Active Learning Centre

A large, flexible classroom, the Active Learning Centre (ALC) will hold up to one hundred people. Equipped with relatively small tables and light, mobile chairs, the room can be quickly configured in rows, groups, a circle, a "U", or any other desired arrangement. The room is also sub-dividable to create separate rooms of approximately 1/3 and 2/3 the original size. With white board and project capability at both ends of the room, the ALC is a versatile space which can be used for teaching, presentations, meetings, or even constructing and testing parts and assemblies. Located along one wall is a series of large lockable cupboards, in which a variety of lab materials, tools, etc. can be stored. Additional storage space is available across the hall in a dedicated storage room, where custom-built trolleys are used 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.

The first year 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. One example of course activity in the room was a second year Mechanical Engineering "Design Techniques" course. The ALC was used for 3 class sections of about 65 students each. With the room arranged to support teams of four, students used this workspace for a variety of "hands on" activity including product dissections and two design projects. For the latter, the ALC was used for idea generation, discussion and sketching of designs, construction of prototypes, and testing of their assemblies. Although the room was somewhat smaller than the room used previously for the same course, the instructor feels that the new facility was conducive to student learning, and that the cupboard and trolley storage system worked well. In addition, the students extensively used the ILC's group rooms for *conceiving* and discussing ideas, the *prototyping centre* (described hereafter) for constructing their designs, and competitively tested them in an organized event held in the ILC *atrium,* to the delight of a mixed audience of students, faculty, and staff who stopped to watch while passing by.

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, the 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 analyze. In so doing, 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 to ensure that students can understand and apply engineering theory, software tools, or other instructional elements. The "just-in-time" delivery of theory captures student attention because they need to understand it immediately, and the subsequent application helps to reinforce the learning.

The teaching studio was well utilized in both academic terms in the first year of operation. Several discussion sessions were held throughout the year with instructors using the studio, and the anecdotal consensus was that while there was a required “learning curve” for both instructors and students, the overall experience was considered to be very positive.

First Year Studios

The ILC includes two “first year studios” which are designed to support the project content of our common first year. Modeled somewhat upon similar facilities at the University of Colorado at Boulder, 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.

Although not fully completed, and therefore not fully utilized during the first year of operation, the first year studios were effective in providing dedicated and convenient workspace for all first year students in one central facility. Furthermore, the regular and frequent presence of these students in the ILC encouraged interaction with upper year students from all disciplines, and exposed them to a variety of multidisciplinary and multi-year activities.

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 use software on the plaza 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 labs, projects or for general study. Throughout the first year of operation, the plazas were well used for curricular activities, and as the year progressed, evening activity became common, particularly in the last few weeks of term and through the exam period.

Design Studio

A “design studio” which is arranged in a manner common in industry practice is housed within the ILC. Open to all discipline 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 four to six 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. The room, like the active learning centre and teaching studio, is elliptical in shape, thus providing creative space for creative thinking. An instructor’s station, large whiteboard, and extensive audio/video equipment are included to accommodate design instruction.

Student use of the design studio grew steadily over the first year. Initially there appeared to be some student resistance to acquiring “I-buttons” for electronic access, which was considered to be required for security reasons. In mid-year, several blocks of “open hours” were assigned, and in parallel student use of I-buttons increased. By the middle of the second term, the design studio was commonly used on both evenings and weekends both by teams and individuals. And as had been hoped, the typical student cross section in the evening or weekend hours was both multidisciplinary and multi-year. The group table arrangements accommodated team discussion and idea generation *(conceiving)*, while the workstations supported extensive *design* and analysis.

Two courses, one in chemical engineering process design and the other a multidisciplinary design fundamentals course, were taught in the design studio in the first year. Both student and instructor feedback on the facility was generally positive, although based on a student exit survey, a small percentage of students commented that the room had visual limitations with the front whiteboard and overheads with small font. This is not a surprising result, given the layout and objectives of this workspace. Based on this feedback, however, software to convey projected images to all desktop monitors will be incorporated for next year.

Prototyping Centre

Directly across the hall from the design studio is the “prototyping centre”. Although there are several departmental machine shops on the Queen’s campus (including an extensive teaching shop in Mechanical & Materials Engineering), only the prototyping centre in the ILC is readily available to all engineering students. In fact, the positioning of this facility just off the main floor atrium, with windows open to the main hall, were designed to encourage student interest and engagement.

The prototyping centre is split such that approximately two-thirds of the space incorporates a small machine shop and fabrication area, and 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.

While not heavily utilized in the first term, the prototyping centre was used extensively in the term two. The rapid prototyping equipment was used by fourteen curricular project teams, as well as two extra-curricular teams. Many of these students made use of the machine shop and fabrication area as well, although the heaviest use of the latter arose from a design/build/test project in a second year Mechanical & Materials Engineering “Design Techniques” course, which also occupied the ILC Active Learning Centre for “lab” activities. These examples clearly indicate the role of the prototyping centre in supporting the *implementation*, and to a lesser extent, *design* and *operation*, of product and system prototypes.

Competitive Team Area

Many Queen’s students are actively involved in extra-curricular 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.

Current project teams housed in the ILC include Solar Car, Concrete Canoe, Aero Design, Concrete Toboggan, Fuel Cell, Glider, and

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 twenty 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 as part of any course.

The multimedia studio supports and encourages the *implementation* of practical presentation skills necessary for effective communication. Although increasing towards the end of the second term, this facility had limited use in the first year of operation.

Site Investigation Facility

A site investigation facility allows samples obtained in fieldwork to be processed, analyzed and stored. It is of interest primarily to students in geological, mining and civil engineering. Typically very "hands-on" activities, the site investigation facility provides students the opportunity to *implement* techniques and *operate* equipment consistent with professional engineering practice in related fields of study. During its first year, it has provided support for first-year team projects carried out in a large marsh northeast of the City Centre.

Live Building

The building's structure and functions contribute to the learning program 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 are 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 (twenty-four 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 website, 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 on-line access to an additional ninety power meters used across campus.

Already a wide variety of student projects from various disciplines and years have used "live building" data from the ILC. The PV array data have been used by several undergraduate student teams, and at least one graduate student. Power consumption data have been used by a team evaluating fuel cell application, by students in upper year energy use project, and by PPS for web displays of energy consumption for public awareness information. The HVAC instrumentation was used for second and fourth year team's projects. Building envelope thermal data are used in a multidisciplinary Instrumentation Lab. And because the data are freely available on-line, it is undoubtedly being viewed for interest, for research, and for student projects beyond our capability to document. 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 and energy use systems.

IN CONCLUSION

In looking back on the first year of operation, it is clear that there has been much progress, and all of our objectives have been at least partially achieved. Feedback from students and instructors using the ILC has generally been positive. Most facilities are well used, and demand is growing. Industry and public awareness and involvement in engineering has been improved. In only its first year of operation, the ILC has already hosted several engineering class project displays to industrial representatives, industry/academic partnering forums, an “Art & Engineering” display, and two dramatic plays open to the public.

The building itself has received international attention. Recognized for its “green” characteristics, the ILC has earned “four leaf” status in a BREEAM evaluation [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 optimize the use of the facilities. For example, motivated by the positive experience of teaching in the new Teaching Studio, one instructor organized 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 Integrated Learning and the ILC have not evolved at the pace or to the degree we would have hoped. Creating a building with exemplary environmental standards has been challenging, and our success, while considerable, is far from total. The obstacles lay in long held opinions and established practices among administrators, architects, engineering consultants and colleagues. Interestingly, this very problem relates to our reasons for incorporating green technology in the building. We believe 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, we hope to overcome the barrier of unfamiliarity, and to educate engineers who are confident of the reliability and aware of the limitations of such technologies.

Anyone interested in adopting some portion of our approach in support of CDIO objectives is welcome to whatever help we can provide. For further information on the Queen’s Integrated Learning Centre in Beamish-Munro Hall, please see http://appsci.queensu.ca/ilc/ or contact either of the authors. Additional ILC contacts are available (http://appsci.queensu.ca/ilc/contacts/team.php)

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