A DESCRIPTION AND ANALYSIS OF MULTIMODAL LEARNING ENVIRONMENTS IN NORTH AMERICA FOR FUTURE CDIO WORKSPACES IMPLEMENTATION

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Abstract

CDIO programs foster active learning and project based courses, which are key for the learning of disciplinary knowledge, design skills and also provide opportunities to improve students' personal and inter-personal skills in an information rich environment. Workspaces that can support this type of hands-on learning are fundamental, and one of the twelve CDIO standards therefore recommends that participating institutions provide workspaces that are student-centered, user-friendly, accessible, and interactive. Workspaces have been developed in many universities worldwide and particularly within institutions collaborating within the CDIO initiative. This paper focuses first on a brief description and comparison of three innovative Multimodal Learning Environments (MLE) in North America, implemented at institutions that are collaborating within the CDIO initiative. These initiatives are the Integrated Teaching and Learning Laboratory (ITLL) at University of Colorado in Boulder (USA), the Aeronautics and Astronautics Learning Laboratory for Complex Systems at the Massachusetts Institute of Technology in Cambridge (USA) and the Integrated Learning Centre (ILC) at Queen's University in Kingston (Canada). The objective of this comparative study is to provide guidelines to the CDIO community for the implementation of such facilities and to bring forward some of the lessons learned generated by these past endeavors. A selected number of quantifiable parameters are proposed and applied to a MLE currently under development at École Polytechnique Montreal. The paper hence proposes a framework, which aims to help future workspaces development by identifying the key characteristics related to the design, implementation and operation of CDIO student multimodal workspaces.

Keywords: Multimodal Learning Environment, Spatial settings, Teaching and learning modes, CDIO workspaces

Introduction

By taking part in the CDIO initiative [1], member institutions acknowledge that design is a team effort and learning to design therefore needs to be situated in real-life problem solving contexts where there are no single right answers [2]. The skills promoted by the CDIO model are therefore developed with a theory to practice a learning approach, where teamwork, experimentation and practical implementation become core educational activities [3].

To achieve these goals, the CDIO approach recognizes the need for participating institutions to support their program reforms with an appropriate learning environment, namely Multimodal Learning Environments (MLE) [1]. An MLE must not only provide an environment for hands-on learning strategies but also opportunities for social learning, that is, settings where students can learn from each other and interact with several groups. The creation of new workspaces, or remodeling of existing laboratories, varies of course with the size of the programs and resources of the institution.

The objective of this paper is to present three existing MLEs in North America and proposes a benchmark for future MLE developments. The Integrated Teaching and Learning Laboratory (ITLL) at the University of Colorado in Boulder (USA), the Learning Laboratory at the MIT Aeronautics and Astronautics Department in Cambridge (USA) and the Integrated Learning Centre (ILC) at Queen's University in Kingston (Canada) were chosen specifically for the comprehensiveness of their approach to workspace development.

The paper will first review the existing MLE descriptions and previous benchmarking attempts [4] [5] [6] in order to propose a more holistic framework articulated around their physical description, their functional description, and their architectural and design process. Finally, a large MLE project currently under development at ÉcolePolytechnique Montreal (Canada) will be used as a case study for the theoretical benchmark outlined in this study. This future project disposes of a 2000 m2 space to implement state of the art CDIO student workspaces and is seen as a perfect opportunity to provide a test case to other academic institutions.

Description of 3 existing Integrated Teaching Laboratories in North America

Standard 6 in the CDIO approach recommends that students *"need to be immersed in workspaces that are organized around the Conceiving- Designing-Implementing-Operating"* phases in order to *"support and encourage hands-on learning of product, process, and system building, disciplinary knowledge, and social learning"* [1].

The development of such a workspace or MLE is therefore typically centered on four different kinds of spaces [5], namely a Concept Forum, a Design Centre, Implementation Laboratories, and an Operations Centre. Figure 1 depicts the conceptual model of CDIO workspaces.

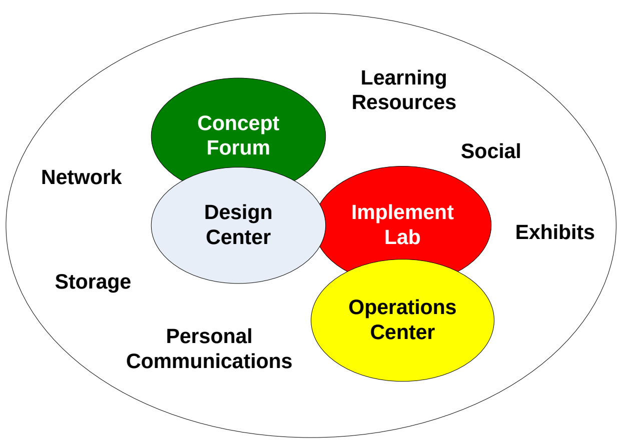


Figure 1: A conceptual model for the development of CDIO workspaces [5]

Before describing the three existing MLEs chosen for this North American study, it is important to note that CDIO guidelines have established a number of common criteria for the development of these workspaces regardless of the engineering discipline [1]. These can be summarized as follows:

- The term MLE must integrate traditional student work areas, team-based project workspaces, computer driven collaborative design rooms, manufacturing and prototyping laboratories, and facilities designed for extracurricular activities.
- CDIO workspaces are designed to support the entire curriculum.
- The new space must facilitate student learning of personal and interpersonal skills, group activities, social interaction, and both collocated and distributed team communication.
- The workspaces should be efficiently connected to other common student facilities, e.g. the library, storage facilities, machine shops, etc.
- A MLE can be built from scratch in a totally new building or can be an adaptation of existing physical layouts (redesign) or can be a combination of both (hybrid).

The three MLEs presented in the following sub-sections follow the above guidelines and represent excellent reference models, which ultimately enabled the authors to elaborate the design and development framework presented in this paper.

The Integrated Teaching and Learning Laboratory at the University of Colorado in Boulder (USA)[6]

The Integrated Teaching and Learning Laboratory (ITLL) is a 3150 ^{m2} (34,400 sq. ft.) hands-on learning facility that opened in January 1997. The architecture of this facility was driven entirely by curricular reform initiatives. It provides students with an interdisciplinary learning arena in which the principles of design are introduced during a student's first year; where theoretical engineering science courses in the middle two years are augmented with hands-on, open-ended discovery opportunities; and where interdisciplinary teams of seniors design, build and test real-world products. As shown in figure 2, the ITLL features first-year design studios, an active learning center, a computer simulation laboratory, an extensive computer network that integrates all the experimental equipment throughout two large laboratory plazas, capstone design studios to showcase student projects, group work areas to support student teams, shops where students turn their dreams into reality and interactive science-based kinetic sculpture galleries. Moreover, the ITLL itself functions as a living laboratory through exposed engineering systems and sensors integrated into the building, making its `pulse' accessible on the Internet as a technology and building systems resource.

This MLE has been in operation for over ten years and it has been extensively used from its inception. Professors Jackie Sullivan and Larry Carlson, co-founders of the ITL Program and Laboratory, recently won the 2008 Bernard M. Gordon Prize for Innovation in Engineering and Technology Education - awarded by the National Academy of Engineering of the USA. This initiative with its first year design course has provento contribute over the yearsto significantly higher retention for all students across the engineering programs and has also fostered hands-on learning of disciplinary subjects.

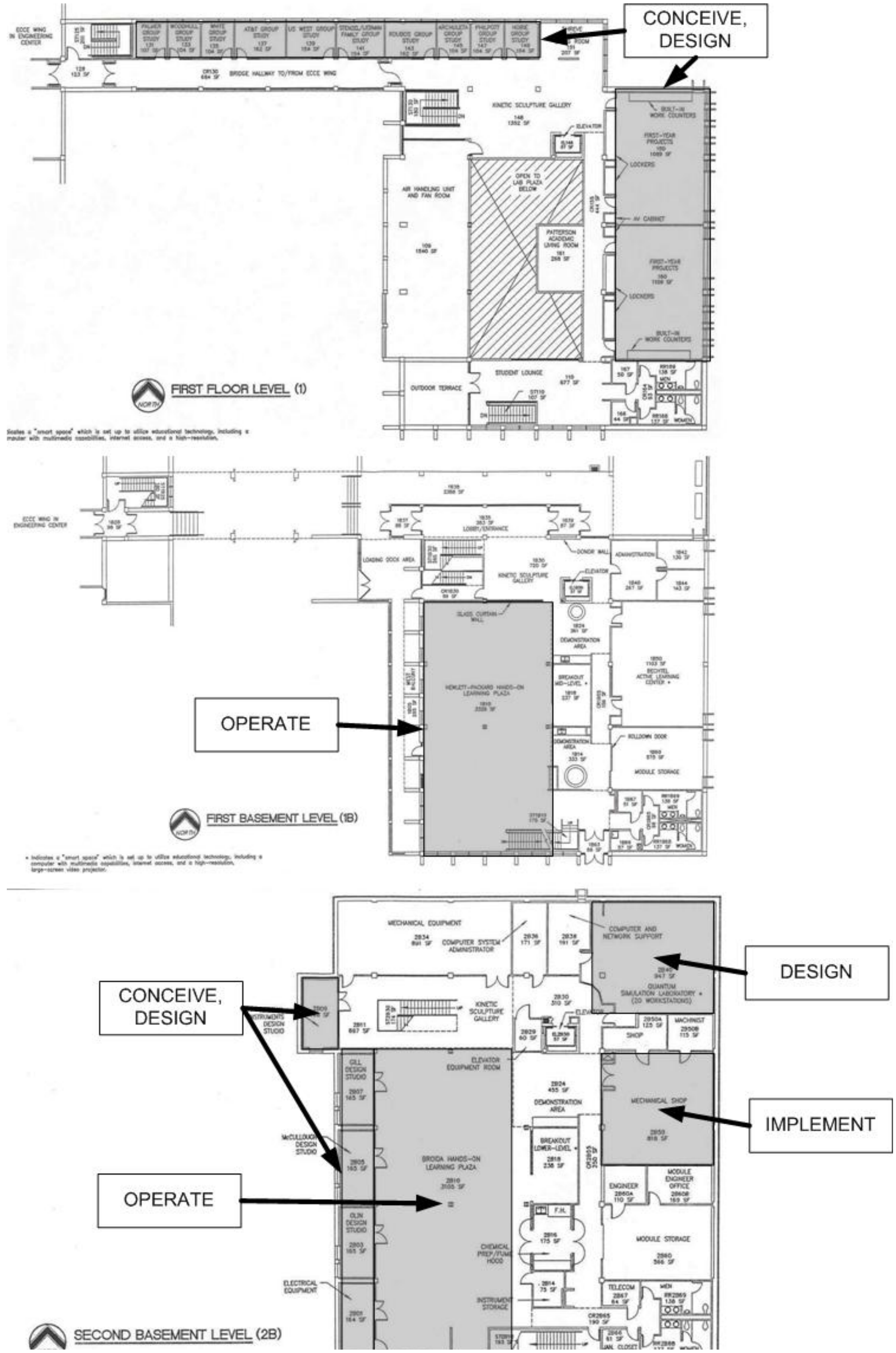


Figure 2: Workspace layout of the Integrated Teaching and Learning Laboratory at the University of Colorado in Boulder (USA)

The Learning Laboratory at the Massachusetts Institute of Technology (USA) [3]

As shown in Figure 3, there are four main spaces associated with the Learning Laboratory in the Aero/Astro department at MIT, which opened in September 2000 within a renovated 1927 building on the main campus. On the third floor, a Concept forum area is available to support the Conceive dimension of the CDIO context. This technology free area allows teams of students to exchange innovative ideas at the conceptual stage of the projects; there are no computer resources available in this design space and the tables can be reorganized at any time to suit team and project sizes. On the second floor is the Digital Design Studio, which supports the Design part of the CDIO context. Modeling and analysis tools are available in this area where teams can meet and work at the same time. On the first floor is the Seamans Laboratory, which houses the Library, a multi-purpose Concept and Management Forum, and a large open space for social interaction and operations, as well as academic support offices. One floor below is the Gelb Laboratory, which is the main implementation space within the CDIO context, with electronics, mechanical and specialty fabrication facilities, as well as an open area for project construction. Adjoining the older building is a new construction — the Newman Hangar — which is a large open space for the execution of large projects and the housing of the two student wind tunnels; it therefore supports the Operate aspects of the CDIO context. The planning of the facility was carried out following a very innovative building development process where 21 learning modes, presented in the next section, were studied and regrouped to establish the structure the Learning Laboratory. An integrated team of client-architect and builder worked from the start on the definition of this MLE as described in [3].

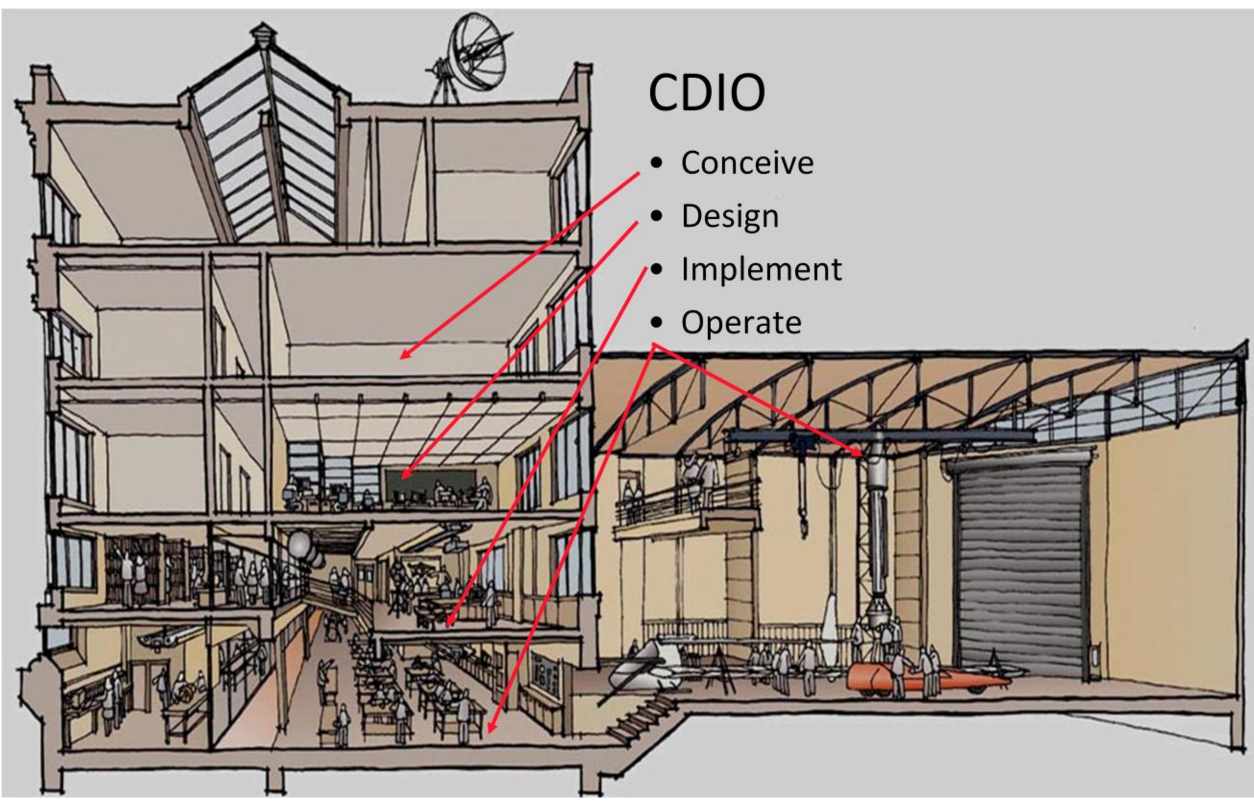


Figure 3: Workspace layout of the Learning Laboratory at MIT (USA)

The Integrated Learning Centre at Queen's University in Kingston (Canada)[4]
At Queen's University, it was recognized early in the development of project-based learning initiatives that existing university facilities would limit the implementation of such innovative teaching methods. Therefore, based on the CDIO objectives and the guiding principles for designing the building, a new, purpose-built facility named Beamish-Munro Hall was constructed to house the Integrated Learning Centre (ILC) which comprises 7500 m^2 of teaching and learning space. Engineering departments at Queen's University have been, and still are, housed in separate buildings on the 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. As shown in figure 4, these include group rooms available to all undergraduate engineering students to meet for team discussions; an active learning centre that will hold up to one hundred people which can be used for teaching, presentations, meetings, or even constructing and testing parts and assemblies; a teaching studio which allows up to 76 students to switch back and forth readily between lecture mode and application mode; two first year studios which can each accommodate about 36 students; "plazas" equipped with instrumented and configurable workbenches suitable for teams of up to four students; a design studio which is arranged in a manner common in industry practice and equipped with powerful computer workstations loaded with a wide variety of design and analysis software; a prototyping centre which incorporates a small machine shop and fabrication area, and the other third houses modern "rapid prototyping" equipment; a multimedia studio seating up to twenty people where students can develop and practice presentation skills thanks to an array of audio-visual equipment; a site investigation facility to allow samples obtained in fieldwork to be processed, analyzed and stored.

Finally, the ILC incorporates an extensive system of sensors to monitor structural, electrical and mechanical elements to provide data for educational and research activities. 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. 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.

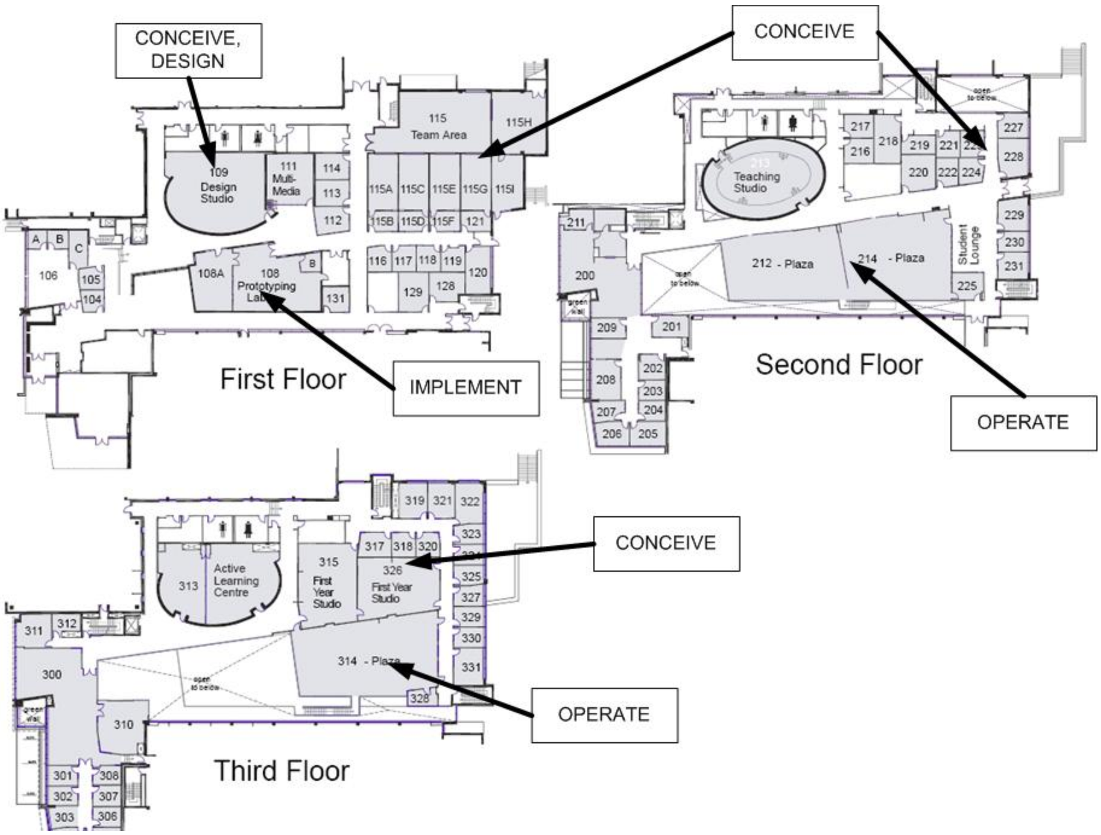


Figure 4: Workspace layout of the Integrated Learning Centre at Queen’s University (Canada)

A framework for future MLE developments

Existing workspaces are likely to be either traditional workshops or formal laboratory space and must therefore be adapted for the type of design-build experience encouraged by the CDIO curriculum. Before presenting a comprehensive framework to support the development of MLEs to meet CDIO standards, a brief review of previous workspace comparative studies, which have influenced the choice of effective spatial settings, is detailed in the next paragraph.

The definition of CDIO teaching and learning modes for an effective choice of spatial settings

A few authors have already published studies of various types of workspaces within the CDIO initiative [4], [5] and [6]. A comprehensive survey of existing workspaces at a given institution has been documented by Wallin and Östlund [7], while a more general survey of workspaces has been conducted by Gunnerson*etal.* [8].

Of particular interest, is the allocation of usage modes to the areas being surveyed in [7]. This approach inspired the definition of 21detailed teaching and learning modes that need to be taken into account for the proper development of CDIO workspaces [3]. These detailed modes were then grouped into 5 major CDIO teaching and learning modes through a preliminary comparative study published by Young *et al* in 2005 [5]. The definition of the major and detailed teaching and learning modes was ultimately refined through the establishment of the formal CDIO standards described in [1].

Table 1 summarizes the links between the 21 detailed CDIO teaching and learning modes and the 5 major CDIO teaching and learning modes. To further the reflection, the authors have associated in table 1 the typical pedagogical activities [9] that relate to each one of the major CDIO teaching and learning modes. Indeed, for the design of spatial settings in an educational environment, a useful classification of pedagogical activities was carried out in [9]. This work resulted in the definition of 5 generic pedagogical activities that need to be addressed for an effective choice of spatial settings and these have been associated with the 5 teaching and learning modes in the table below.

Table 1. CDIO teaching and learning modes related to typical pedagogical activities

Major CDIO teaching and learning modes [1]	Detailed CDIO teaching and learning modes [1]	Related pedagogical activities [9]
Product and system design and implementation	Advanced design-implement project Simple design-implement project Collaborative project Extracurricular design project Test & Operate Tinkering Linked projects	Creating, Applying, Communicating
Reinforcement of disciplinary knowledge	Lecture/Presentation Class Lab/Experiment Teaching in Labs Interactive Electronic Class Self-Directed Learning Distance Learning	Delivering, Applying
Knowledge discovery	Undergraduate research project Graduate research project	Creating, Applying
Community building	Linked projects Distance Learning Advanced design-implement project Simple design-implement project Collaborative project Extracurricular design project	Creating, Communicating, Delivering, Decision making
Auxiliary issues	Research design support Income generating Outreach	Creating, Applying Communicating, Delivering, Decision making

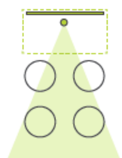
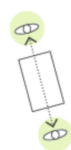
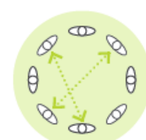
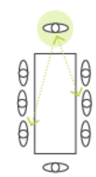
Based on [9], the 5 pedagogical activities found in any educational environment can be defined as follows:

- Applying: refers to controlled activities where knowledge is passed on in an active “master & apprentice” learning mode through demonstrations and laboratory type experiments.
- Communicating: knowledge is dispersed and shared through synchronous information exchanges, such as debates, discussions or team meetings.
- Creating: activities where abstract knowledge is used to innovate and ideas transformed into a product. These are highly active learning activities.

- Decision making: knowledge is dispersed and the information needs to be shared through a review setting. These activities result in the generation of strategies, the implementation of a course of action and decisions.
- Delivering: activities to transfer knowledge to a group through formal presentations in a passive learning mode.

Table 2 presents a pictorial illustration of conceptual spatial settings that should be associated to each aforementioned pedagogical activity [9]. Of course, these concepts need to be customized and combined in order to match the CDIO teaching and learning modes, as proposed in table 1. The relationships hence established can be useful to define an MLE layout and multiple spatial settings can be used to maximize the usage flexibility of workspaces.

Table 2. Linking pedagogical activities to spatial settings [9]

	Delivering	Applying	Creating	Communicating	Decision making
Spatial settings					

Towards adesign and development framework for efficient MLE implementation

Young et al [5] presented a comparative table of various workspaces within the CDIO initiative. This type of benchmarking tool is very useful to compare workspaces and has been used as a basis for the comparison of the three North American ILCs. The format has however been adjusted to regroup the various contents in three main categories: the physical description, the functional description and finally the architectural and design process as shown in Table 3. The learning modes are a very important aspect of the classification and they have been updated to the classes used in [1]. These modes are also ordered by priority of usage. This ordering provides a better understanding of the importance of the various activities supported by the various MLEs. Even though these three initiatives have much in common, there are significant differences in a number of descriptive criteria. They share a wide variety of active learning modes and workspaces that encompasses CDIO activitiesrelated to projects, as shown previously in Figures 2, 3 and 4. They also integrate other active learning modes, which are very important as shown by the priorities of their supported learning modes. They thus all support a very high level of multimodal learning activities that goes beyond the sole support of CDIO projects.

Table 3. Comparison of the three major North-American MLEs

	Integrated Teaching and Learning Laboratory at the University of Colorado in Boulder	MIT Aero/Astro Learning Laboratory for Complex Systems	Integrated Learning Centre, Queen's, Kingston
Physical description			
Inaugurated	1997	2000	2004
Type of building	Live	Standard	Green/Live
Total space [m2]	3160	2170	7500
# of floors	3	3 + 1	3
Special equipment and facilities	Custom laboratory instrumented benches for active learning of disciplinary subjects	Hangar, library and Operational content	Large number of breakout rooms, teaching studios
Most flexible spaces	Teaching plazas and project areas	Large open-space bays, library and operational areas	Teaching plazas and project areas
Functional description			
Programs	All	Aero/Astro	All
Courses/projects	20	5	60
Program years	1-4, K12	1-4, graduate	1-4, K12
CDIO Workspaces	C-D-I-O	C-D-I-O	C-D-I-O
Disciplinary teaching and learning	Many courses	No	Many courses
Learning modes (in ascending order of importance 1 being the highest usage)	1) Reinforcement of disciplinary knowledge	1) Product and system design and implementation	1) Product and system design and implementation
	2) Knowledge discovery	2) Knowledge discovery	2) Reinforcement of disciplinary knowledge
	3) Product and system design and implementation	3) Reinforcement of disciplinary knowledge	3) Community building
	4) Community building	4) Community building	4) Knowledge discovery
	5) Auxiliary issues	5) Auxiliary issues	5) Auxiliary issues
Access hours	As much as safety permits	24/7 access to most areas; 8-5 access to machine shop	Long hours, 7 days a week as much as safety and security permit + 24/7 on for design/build projects as needed
Architectural and design process			
Initial investment cost (MSD) (total)	18M$	15M$	25M$
Design approach: New (building)**, Redsign** (of existing space)**, Hybrid** (new+redesign)	New	Hybrid	Hybrid
Originality of the Architectural Design Process	First known in North-America to implement integrated teaching and learning workspaces to that extent	Developed an innovative design process for such a facility	Architects gave great attention to make building attractive to students
	Students involved from the beginning	Integrated team of client-architect-builder	Focus on common first year learning and teaching
	Driven entirely by curricular reform objectives	Focus on learning modes for the design of the new spaces	

The future MLE at ÉcolePolytechnique Montreal (Canada)
To test the proposed framework, the aforementioned comparative table was used as a benchmarkfor the development of the CDIO MLE at ÉcolePolytechnique de Montréal. The resulting detailed layout is shown in Figure 5. The construction work is scheduled to start in June 2008 and will be completed over the next few years in various phases. The initiative comprises 2000 m^2 of active learning workspace. The area on the right includes two project areas sharing a common manufacturing laboratory. The project area at the bottom is for 1st and 2nd year projects. The team areas can accommodate up to 6 students per team and the partitions are adjustable to increase the flexibility of the workspace. The project area at the top is designed for 4th year large-scale projects. The layout is very flexible and it can accommodate teams of 5 to 15 students. Teams can use white boards for their design work. These are installed along the walls and on the partitions that are all movable. The design room also includes workbenches that can be moved to the team areas when required. The workspace is thus completely reconfigurable. The area in the centre comprises a number of break rooms that can be reserved by the teams; all rooms in this area are equipped with digital modeling and analysis tools. The area on the left comprises active learning areas for strength of materials, instrumentation, rapid prototyping, electronics and mechatronics. Some of these laboratories can also support design-build projects. A CDIO agora is included at the entrance of this facility. The agora will display operational products with corresponding digital mock-ups and simulations.

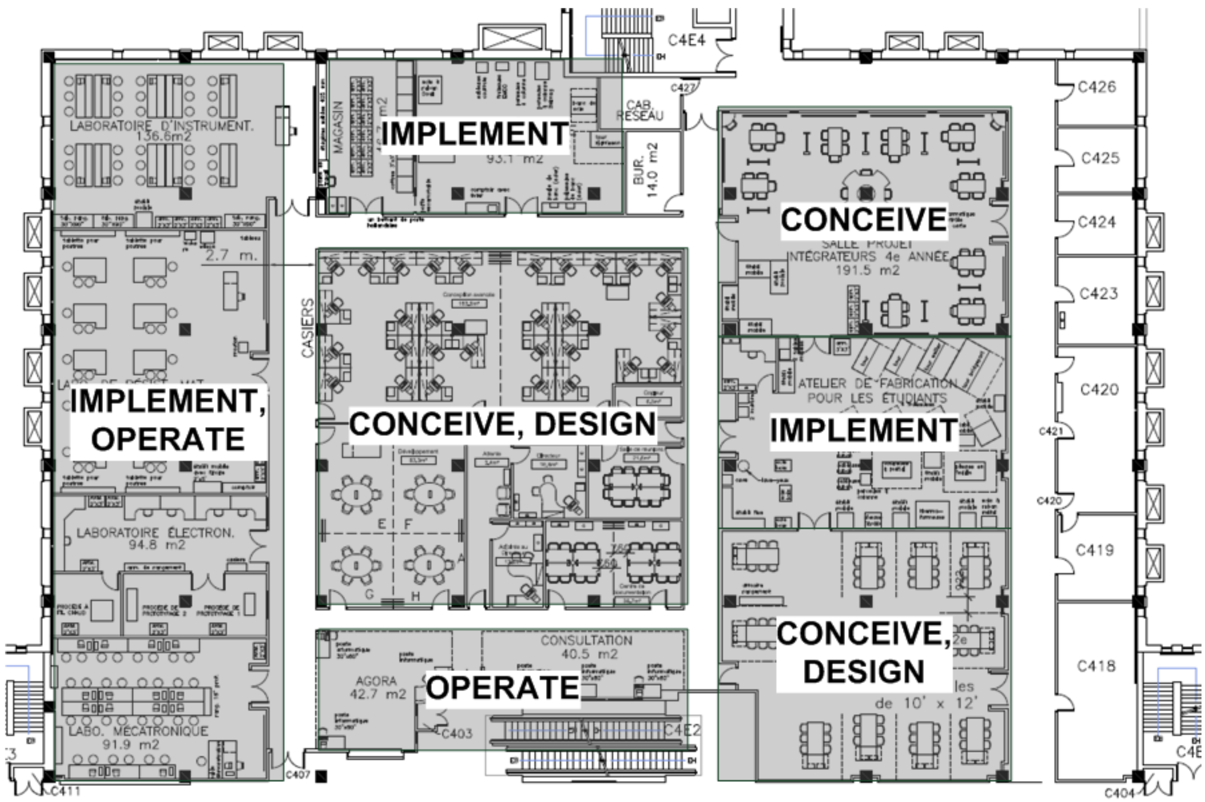


Figure 5: Workspace layout of the CDIO Multimodal Learning Environment at ÉcolePolytechnique Montreal (Canada)

The facility will be able to support multiple modes of learning and the benchmark described previously has been used to evaluate this new implementation with respect to the three major

MLEs described in the previous section. The updated comparison is presented in Table 4. Many characteristics can be reviewed and compared to benchmark any new project with some of the best existing facilities.It fosters a best practice approach for MLE development within the CDIO initiative and other implementations can be used in the table as reference.

Table 4. Comparison of the 3 major with a new initiative at ÉcolePolytechnique

	Integrated Teaching and Learning Laboratory at the University of Colorado in Boulder	MIT Aero/Astro Learning Laboratory for Complex Systems	Integrated Learning Centre, Queen's, Kingston	École Polytechnique, Montreal
Physical description				
Inaugurated	1997	2000	2004	2009
Type of building	Live	Standard	Green/Live	Standard
Total space [m2]	3160	2170	7500	2000
# of floors	3	3 + 1	3	1
Special equipment and facilities	Custom laboratory instrumented benches for active learning of disciplinary subjects	Hangar, library and Operational content	Large number of breakout rooms, teaching studios	Virtual environment for product development
Most flexible spaces	Teaching plazas and project areas	Large open-space bays, library and operational areas	Teaching plazas and project areas	Integrated project area and CDIO agora
Functional description				
Programs	All	Aero/Astro	All	Mech + Aero + multi-disciplinary
Courses/projects	20	5	60	10
Program years	1-4, K12	1-4, graduate	1-4, K12	1-4, graduate
CDIO Workspaces	C-D-I-O	C-D-I-O	C-D-I-O	C-D-I-O
Disciplinary teaching and learning	Many courses	No	Many courses	Laboratories
Learning modes (in ascending order of importance 1 being the highest usage)	1) Reinforcement of disciplinary knowledge	1) Product and system design and implementation	1) Product and system design and implementation	1) Product and system design and implementation
	2) Knowledge discovery	2) Knowledge discovery	2) Reinforcement of disciplinary knowledge	2) Reinforcement of disciplinary knowledge
	3) Product and system design and implementation	3) Reinforcement of disciplinary knowledge	3) Community building	3) Community building (under evaluation)
	4) Community building	4) Community building	4) Knowledge discovery	4) Knowledge discovery
	5) Auxiliary issues	5) Auxiliary issues	5) Auxiliary issues	5) Auxiliary issues
Access hours	As much as safety permits	24/7 access to most areas; 8-5 access to machine shop	Long hours, 7 days a week as much as safety and security permit + 24/7 on for design/build projects as needed	24/7 depending on areas - as much as safety and secutity permit
Architectural and design process				
Initial investment cost (MSD) (total)	18M$	15M$	25M$	9M$
Design approach: New (building)**, Redsign** (of existing space)**, Hybrid** (new+redesign)	New	Hybrid	Hybrid	Redesign
Originality of the Architectural Design Process	First known in North-America to implement integrated teaching and learning workspaces to that extent	Developed an innovative design process for such a facility	Architects gave great attention to make building attractive to students	Emphasis on fostering innovation and proximity of project workspaces to virtual environment and implementation workspaces
	Students involved from the beginning	Integrated team of client-architect-builder	Focus on common first year learning and teaching	Standard design process
	Driven entirely by curricular reform objectives	Focus on learning modes for the design of the new spaces		

The framework can also be used as a very efficient communication tool to convey the complex and powerful teaching mechanisms that can be supported by such a facility. It effectively provides in a condensed format the most important parameters of such an MLE implementation.

Conclusion

Even though large capital investments are not necessarily required to implement CDIO workspaces, the three large North American MLEs studied were selected for the comprehensiveness of their implementation. Their analysis and comparison has been shown to provide excellent examples of workspace physical characteristics, functional usage and architectural and development process. This top down approach provides a high level view of the topic and it would be useful to extend this work to more detailed descriptions of particular types of workspaces such as design-build project areas, storage space and break-out rooms. More work is certainly required in these areas.

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