The Gordon-MIT Engineering Leadership Program: Relationship to CDIO Syllabus v2

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ABSTRACT

In June 2011, version 2.0 of the CDIO Syllabus was released, which contained updated and expanded information, including an extension on Leadership and Entrepreneurship. Comparing the structure of the CDIO Syllabus with the Bernard M. Gordon-MIT Engineering Leadership Program's (Gordon-MIT ELP) fundamental document, *Capabilities of Effective Engineering Leaders,* reveals a great deal of overlap. The Gordon-MIT ELP has created a curriculum for undergraduate engineering students based on these *Capabilities* and has delivered it to hundreds of students to date. This paper will illustrate the connections among the CDIO Syllabus, the *Capabilities of Effective Engineering Leaders* document, and the curriculum and curricular elements of the Gordon Engineering Leaders (GEL) component of the Gordon-MIT ELP.

KEYWORDS

Leadership, Curriculum, Capabilities, Syllabus

INTRODUCTION

The addition of Leadership and Entrepreneurship to the CDIO Syllabus is reflective of the changing role of the engineer. New skills will be necessary as "explosive advances in knowledge, instrumentation, communication, and computational capabilities create a mind-boggling playing field for the next generation" [1]. For the next generation of engineering leaders to truly seize these groundbreaking opportunities, they will need to be able to "organize effort, create vision, and facilitate the work of others" [2].

Undergraduate programs educating future engineers need to embrace these changing roles and adequately prepare their students to fill them. The goals of CDIO Initiative programs and the Bernard M. Gordon-MIT Engineering Leadership Program (Gordon-MIT ELP) are quite similar:
Educate engineers to lead in the *creation and operation* of new products and system (CDIO),
and
Educate and develop the character of outstanding MIT students as the potential future leaders of engineering practice and development (Gordon ELP).

COMPARISON OF CAPABILITIES AND CDIO SYLLABUS v2 TOPICS

Since the goals are so similar, it comes as no surprise then that Version 2.0 of the CDIO Syllabus (with the extension) overlaps extensively with, and indeed captures most of the ideas contained in the foundational document *Capabilities of Effective Engineering Leaders* upon which the curriculum of the Gordon-MIT ELP is based. See Table 1 below for the list of Capabilities. Engineering leadership is defined by the Gordon-MIT ELP as "the technical leadership of change: the *innovative* conception, design and *implementation* of new products/ processes/ projects/materials/molecules/software/systems, supported by the *invention* of enabling technologies, to meet the needs of customers and society" [4].

Table 1: Comparing *Capabilities of Effective Engineering Leaders and CDIO Syllabus v2*

Capabilities of Effective Engineering Leaders	*CDIO Syllabus v2*
THE ATTITUTES OF LEADERSHIP – CORE PERSONAL VALUES AND CHARACTER: • Initiative • Decision Making in the Face of Uncertainty • Responsibility, Urgency and Will to Deliver • Resourcefulness, Flexibility and Change • Ethical Action, Integrity and Courage • Trust and Loyalty • Equity and Diversity • Vision and Intention in Life • Self-Awareness and Self-Improvement	**2.4 ATTITUDES, THOUGHT AND LEARNING** 2.4.1 Initiative and the Willingness to Make Decisions in the Face of Uncertainty 2.4.2 Perseverance, Urgency and Will to Deliver, Resourcefulness and Flexibility 2.4.5 Self-awareness, Metacognition and Knowledge Integration 2.4.6 Curiosity and Lifelong Learning **2.5 ETHICS, EQUITY AND OTHER RESPONSIBILITIES** 2.5.1 Ethics, Integrity and Social Responsibility 2.5.2 Professional Behavior 2.5.3 Proactively Planning for One's Career 2.5.4 Staying Current on World of Engineer 2.5.5 Equity and Diversity 2.5.6 Trust and Loyalty
RELATING: • Inquiring and Dialoging • Negotiation, Compromise and Conflict Resolution • Advocacy • Diverse Connections and Grouping • Interpersonal Skills • Structured Communications	**3.1 TEAMWORK** 3.1.1 Forming Effective Teams 3.1.2 Team Operation 3.1.3 Team Growth and Evolution 3.1.4 Team Leadership 3.1.5 Technical and Multidisciplinary Teaming **3.2 COMMUNICATIONS** 3.2.1 Communications Strategy 3.2.2 Communications Structure 3.2.3 Written Communication 3.2.4 Electronic/Multimedia Communication 3.2.5 Graphical Communication 3.2.6 Oral Presentation 3.2.7 Inquiry, Listening and Dialog 3.2.8 Negotiation, Compromise and Conflict Resolution 3.2.9 Advocacy 3.2.10 Establishing Diverse Connections and Networking
MAKING SENSE OF CONTEXT: • Awareness of the Societal and Natural Context • Awareness of the Needs of the Customer or Beneficiary • Enterprise Awareness	**2.3 SYSTEM THINKING** 2.3.1 Thinking Holistically 2.3.2 Emergence and Interactions in Systems 2.3.3 Prioritization and Focus 2.3.4 Trade-offs, Judgment and Balance in

• Appreciating New Technology • Systems Thinking	Resolution **4.1 EXTERNAL, SOCIETAL, AND ENVIRONMENTAL CONTEXT** 4.1.1 Roles and Responsibility of Engineers 4.1.2. The Impact of Engineering on Society 4.1.3. Society's Regulation of Engineering 4.1.4. The Historical and Cultural Context 4.1.5 Contemporary Issues and Values 4.1.6. Developing a Global Perspective **4.2 ENTERPRISE AND BUSINESS CONTEXT** 4.2.1 Appreciating Different Enterprise Cultures 4.2.2 Enterprise Stakeholders, Strategy and Goals 4.2.4 Working in Organizations 4.2.5 Working in International Organizations 4.2.6 New Technology Development and Assessment **4.3 CONCEIVING, SYSTEMS ENGINEERING AND MANAGEMENT** 4.3.1 Understanding Needs and Setting Goals 4.3.3 System Engineering, Modeling and Interfaces
VISIONING: • Identifying the Issue, Problem or Paradox • Thinking Creatively, and Imagining and Communicating Possibilities • Defining the Solution • Creating the Solution Concept	**2.4 ATTITUDES, THOUGHT AND LEARNING** 2.4.3 Creative Thinking **4.3 CONCEIVING, SYSTEMS ENGINEERING AND MANAGEMENT** 4.3.1 Understanding Needs and Setting Goals 4.3.2 Defining Function, Concept and Architecture 4.3.3 System Engineering, Modeling and Interfaces **4.4 DESIGNING** 4.4.1 The Design Process 4.4.2 The Design Process Phasing and Approaches 4.4.3 Utilization of Knowledge in Design 4.4.4 Disciplinary Design 4.4.5 Multidisciplinary Design 4.4.6 Design for Sustainability, Safety, Aesthetics, Operability and other Objectives **4.7 LEADING ENGINEERING ENDEAVORS** **Creating a Purposeful Vision** 4.7.1 Identifying the Issue, Problem or Paradox 4.7.2 Thinking Creatively and Communicating Possibilities 4.7.3 Defining the Solution 4.7.4 Creating New Solution Concepts
DELIVERING ON THE VISION: • Building and Leading an Organization and Extended Organization • Planning and Managing a Project to Completion • Exercising Project/Solution Judgment and Critical Reasoning • Innovation	**2.4 ATTITUDES, THOUGHT AND LEARNING** 2.4.4 Critical Thinking 2.4.7 Time and Resource Management **2.5 ETHICS, EQUITY AND OTHER RESPONSIBILITIES** 2.5.3 Proactive Vision and Intention in Life

• Invention • Implementation and Operation	**4.2 ENTERPRISE AND BUSINESS CONTEXT** 4.2.4 Working Successfully in Organizations **4.3 CONCEIVING, SYSTEMS ENGINEERING AND MANAGEMENT** 4.3.3 System Engineering, Modeling and Interfaces 4.3.4 Development Project Management **4.4 DESIGNING** 4.4.1 The Design Process 4.4.2 The Design Process Phasing and Approaches 4.4.3 Utilization of Knowledge in Design 4.4.4 Disciplinary Design 4.4.5 Multidisciplinary Design 4.4.6 Design for Sustainability, Safety, Aesthetics, Operability and other Objectives **4.5 IMPLEMENTING** 4.5.1. Designing the Implementation Process **4.7 LEADING ENGINEERING ENDEAVORS** **Delivering on the Vision** 4.7.5 Building and Leading an Organization and Extended Organization 4.7.6 Planning and Managing a Project to Completion 4.7.7 Exercising Project/Solution Judgment and Critical Reasoning 4.7.8 Innovation – the Conception, Design and Introduction of New Goods and Services 4.7.9 Invention – the Development of New Devices, Materials or Processes that Enable New Goods and Services 4.7.10 Implementation and Operation – the Creation and Operation of the Goods and Services that will Deliver Value
TECHNICAL KNOWLEDGE AND REASONING	**DISCIPLINARY KNOWLEDGE AND REASONING**

The creation of the *Capabilities of Effective Engineering Leaders* was based on a skills-based model of leadership – the Four Capabilities model, developed at the MIT Sloan School of Management [3]. Using the Four Capabilities model and its underlying scholarship as a basis, a series of workshops were held during the Winter and Spring of 2008. Workshop participants were program stakeholders holding multiple perspectives of engineering leadership, including: MIT alumni, students, faculty, leaders from industry, military leaders, community leaders and those from other leadership programs at MIT [4]. The first draft of the *Capabilities of Effective Engineering Leaders* emerged as a consensus from this group. Through continued engagement with stakeholders, the document has continued to develop. The curriculum of the Gordon Engineering Leaders (GEL) component of the Gordon-MIT ELP was designed to incorporate the thirty Capabilities described in the document. Ideally, students graduating from the GEL program will have developed "the *attitudes* of leadership: core values and character…the *skills* of leadership…under the headings of: relating to others, making sense of context, creating visions and realizing the vision" [4]. This will be coupled with a "deep understanding of the underlying *knowledge* of engineering, science and technology" [4].

CURRICULUM OF THE GEL COMPONENT OF THE GORDON-MIT ELP

We have created several approaches to help different groups of students develop these Capabilities. This paper will focus on the Gordon Engineering Leader program (GEL), which is a co-curricular program with one-year and two-year options. The GEL component links a) immersive experiences on- and off-campus in which students practice, observe, and discuss engineering leadership with b) courses that provide conceptual and analytical models and frameworks that support engineering leadership with c) reflection, evaluation and feedback from faculty, peers, and experienced engineering industry mentors on lessons learned from leadership activities. Table 2 portrays a broad overview of the intersection of Capabilities and the curriculum.

The GEL Year One (GEL1) program consists of courses in engineering leadership (EL) and engineering innovation and design (EID), hands-on engineering leadership labs (ELL) and projects (EPR), mentorships (Mntr), and a personal leadership development plan (PLDP). The students participate in guided reflection on their successes and discover opportunities for improvement. Mentors, faculty, staff, peers and program alumni provide guidance in reflecting on and learning from leadership experiences. Students who successfully complete the GEL1 requirements may apply for the more intensive GEL Year Two (GEL2). GEL2s take courses in project engineering (ProjEng) and planning, and human and organizational contexts (P&O), participate more extensively in engineering leadership labs and projects, complete a summer internship (Intr+), receive additional mentoring and coaching, fulfill more leadership roles, and create a compelling final presentation of their personal leadership development plan.

Table 2: Where Capabilities and Curriculum Meet – A Broad Overview

L= Learn P=Practice R = Reflect

Capability	EID	EL	Proj Eng	P&O	ELL	EPR	Intrn+	PLDP	Mntr
Attitudes of Leadership: Core Personal Values and Character • Initiative (2.4.1) • Decision Making in the Face of Uncertainty (2.4.1) • Responsibility, Urgency and Will to Deliver (2.4.2) • Resourcefulness, Flexibility and Change (2.4.2) • Ethical Action, Integrity and Courage (2.5.1) • Trust and Loyalty (2.5.6) • Equity and Diversity (2.5.5) • Vision and Intention in Life (2.5.3) • Self-Awareness and Self-Improvement (2.4.5, 2.4.6, 2.5.3, 2.5.4)					P, R	P	P	R	R
Relating • Inquiring and Dialoging (3.2.7) • Negotiation, Compromise and Conflict Resolution (3.2.8) • Advocacy (3.2.9) • Diverse Connections and Grouping (3.2.10) • Interpersonal Skills (3.1) • Structured Communications (3.2)	L			L	P, R	P	P	R	R
Making Sense of Context	L, P	L		L	P, R	P	P	R	R

• Awareness of the Societal and Natural Context (4.1) • Awareness of the Needs of the Customer or Beneficiary (4.3.1) • Enterprise Awareness (4.2) • Appreciating New Technology (4.2.6) • Systems Thinking (2.3, 4.3.3)									
Visioning • Identifying the Issue, Problem or Paradox (4.3.1, 4.4, 4.7.1) • Thinking Creatively, and Imagining and Communicating Possibilities (2.4.3, 4.4, 4.7.2) • Defining the Solution (4.3.1, 4.7.3) • Creating the Solution Concept (4.3.2, 4.3.3, 4.7.4)	L	L			P, R	P		R	R
Delivering on the Vision • Building and Leading an Organization and Extended Organization (4.2.4, 4.7.5) • Planning and Managing a Project to Completion (2.4.7, 4.3.4, 4.7.6) • Exercising Project /Solution Judgment and Critical Thinking (2.4.4, 4.7.7) • Innovation (4.4, 4.7.8) • Invention (4.7.9) • Implementation & Operation (4.5.1, 4.7.10)	L, P	L, P, R	L	L	P, R	P	P	R	R

Engineering Leadership Labs - ELLs

One distinguishing element in the GEL program component is the inclusion of experiential learning opportunities for the development of our engineering leadership Capabilities in the weekly two-hour Engineering Leadership Laboratories (ELLs). GEL1s (two semesters) and GEL2s (four semesters) fully participate in ELLs that are designed to provide practice in one or more of the Capabilities. Small teams of GELs are given engineering situations and challenges. The assignment of team leader rotates among the GELs, thus giving all team members several opportunities to be the team leader in each semester. The situations, often designed in collaboration with practicing engineers, are set in a context that provides a feeling of authentic industry practice (e.g. selecting a material for automobile head lights; setting up an assembly process for simple testing devices. The team leaders are observed by faculty, staff, GEL alums, or guest engineers, an engineering leadership capability assessment card is completed, and team leaders and evaluators have private discussions of the leader's performance, including what went well, what did not go well, and what will go differently at the next leadership opportunity. Students also reflect on their performance and complete a reflection document.

GEL2s also act as a cadre, helping run most of the ELLs, providing support for the GEL program outreach and teambuilding events, and designing and running one ELL each semester entirely on their own.

Courses

There are four courses in the GEL component of the Gordon-MIT Engineering Leadership Program; the first two described below are taken by GEL1 students and the next two are taken by GEL2 students.

Engineering Leadership: Delivering Engineering Success (EL) introduces models and theories of leadership/engineering leadership, including Sloan's Four Capabilities Framework and the *Capabilities of Effective Engineering Leaders* (Gordon-MIT ELP), among others. Focuses on describing and identifying essential skills of leadership in current practicing engineers and within historical engineering case studies. Includes sections on Critical thinking, System thinking, Decision making in the presence of uncertainty and Effective communication of information. Is typically taught in an intensive five full-day format.

Engineering Innovation and Design (EID) is a project-based seminar developing skills to effectively conceive, evaluate, plan, organize, lead, and implement engineering design projects. Includes techniques to sharpen creative thinking and critical analysis of designs, as well as utilize iterative processes. Students innovate, implement, and communicate designs that are practical, successful, elegant, interactive, robust, and holistic. Focus on project scope, and balancing real-world constraints against the limitations of technology and human cognition.

Project Engineering and Management (ProjEng) helps students to decompose a project into work packages, map these to an appropriate organizational structure and understand the typical contractual arrangements for doing so in the real world; Plan the work to be done by creating a project plan, a schedule and a budget, along with major milestones; Identify the critical path(s) in the project as well as metrics and methods for measuring progress during project execution; Identify risks in projects, including unplanned rework and iterations and be aware of typical mitigation strategies; Appreciate the larger challenges of projects in the context of international engagements, project finance and stakeholder uncertainty; Appreciate the need for post-projects assessment and learning. Is typically taught in an intensive four-day workshop format.

People and Organizations (P&O) provides an understanding of the human and organizational contexts in which you will be working and the skills you will need to be productive and successful as you enter the world of work and throughout your career; Explores how to put the scientific, technical and organizational knowledge learned at MIT to work in addressing the major challenges facing management and organizations today.

Other Curricular Elements

There are several other required elements in the GEL curriculum that GEL1s and GEL2s participate in at various levels. For the engineering practice requirement (EPR), all GEL students participate in one or two realistic scale project experiences with an engineering component which taken together with other undergraduate experiences, will fulfill three of the six requirements that students work:

a. As an established leader of a team
b. With peers with other disciplinary backgrounds and skills (*e.g.,* other engineering disciplines, business, law, etc.)
c. With colleagues from diverse backgrounds (*e.g*., not from research intensive universities)
d. On a real industrial deliverable
e. On a deliverable that is delivered on schedule, to specification and to cost (mandatory)
f. On a project with international components and perspectives

The Personal Leadership Development Plan (PLDP) has two main purposes: to *familiarize*

students with the Capabilities of an engineering leader, and *encourage* them to plan for their personal and professional development. It is a self-reflective framework. GEL1s complete and submit the PLDP, and GEL2s also make a compelling presentation of their PLDPs.

GEL has partnered with MIT faculty, graduate students, industry members, and others to offer mentors to GEL students (Mntr). These mentors are available to advise and assist students in their self-reflection and development as engineering leaders, both in the program and on projects outside of GEL.

GEL2s must actively seek out and participate in an internship with industry the summer after their junior year (Intrn+). To receive a GEL Year Two certificate and to develop additional documentation/artifacts for use with the PLDP, GEL2s submit an initial and a final report to demonstrate that they have taken the necessary steps with the company and/or supervisor to ensure that they maximize their experience so that it is beyond an ordinary internship.

Evaluation of the GEL Component

Given the relatively young age of the GEL component, it is too early to judge the careers of our students. The first cohort entered an earlier incarnation of the two-year program in Fall 2008, finishing in Spring 2010. However, anecdotal evidence of the GEL component is available and includes a GEL student who approached a major telecommunications CEO with an idea during her summer internship. The idea, involving substantial investment by the company, has since been implemented and she continues to be involved, in a leadership capacity. Reviews from internship managers, mentors, and executives indicate GEL students have done well in other companies. GEL students receive employment offers from companies impressed with their internship performance. Also, companies who have sponsored our GELs as interns, in addition to requesting more interns, have become involved as mentors, ELL observers/ evaluators, guest speakers, or providers of authentic data/information from which we construct the real world flavor of the ELLs.

GEL component success is also noted by over 80% of applicants citing strong recommendations from current students as the primary reason for applying. Program admissions increased from: 17 in year 1, 35 in year 2, 70 in year 3, 115 in year 4, and 120 in year 5. In years 1 and 2 only the two-year version was available, and in Fall 2010 the one-year version was launched. Since the GEL component began, 37 students have received a GEL1 certificate and 42 students have received a GEL2 certificate. In May 2013 it is expected that approximately 50 students will receive a GEL1 certificate and approximately 25 students will receive a GEL2 certificate.

Quantitative assessment of leadership self-efficacy included a pre/post-test survey in 2010-2011; GELs rated their self-confidence from 0% to 100% that they could “Persuade a team to give up on an approach that at the moment only you see why it cannot succeed “, and “Help team members arguing for very different strategies arrive at a choice they can all support”. Confidence for these and most other statements increased significantly over the year, but the change for the statement “Raise critical questions that reveal both strengths and weaknesses of a team member’s new idea” did not, leading to a strengthening of the ELL on inquiry/ dialoguing/advocacy [5].

On a Spring 2010 survey of all graduating MIT seniors, GELs had higher confidence of accomplishing the tasks below than non-GELs in engineering departments, and higher confidence than graduating seniors in the Sloan School of Management: 1) “Make firm

decisions and take action even if some of the facts about the best choice are not clear" and 2)"Recognize when you should stop talking about improvements and focus on what can be fully implemented" [6].

OTHER COMPONENTS OF THE GORDON-MIT ELP

We have created several approaches to help non-GEL students develop the engineering leadership Capabilities, with a special emphasis on students in team-based project-based courses. We partner with departments to promote engineering leadership Capability development by providing activities, class sessions, materials, and workshops on leadership, teamwork, and project engineering for faculty to use in their classes, or alternatively, we provide staff to run these activities in classes at the request of the faculty. In collaboration with the School of Engineering, we coordinate the funding and training of teaching assistants specifically to facilitate student teams in project-based courses. Our course, *Engineering Innovation and Design*, is open-enrollment and available to non-GELs; with a freshmen version being offered experimentally in Spring 2013. We are always considering options to reach all the engineering students at MIT.

A professional education program aimed at early-career engineers is currently under development. A five-day pilot class was successfully completed by 30 participants at an industry-partner site in Fall 2012. A second offering will take place at MIT in June 2013 through MIT's Professional Education program.

In response to our higher education colleagues' request for information, several workshops are being developed, geared to university faculty and staff who would like to know more about the details of Gordon-MIT ELP and perhaps create a similar program at their university. The first offering of the one-day workshop will be held in June 2013 at MIT.

CONCLUSION

The connections among the *CDIO Syllabus v2.0*, the *Capabilities of Effective Engineering Leaders*, and the curriculum and curricular elements of Gordon-MIT ELP are numerous and robust. This paper illustrates these connections and provides some details regarding curricular content and approach of the GEL component of the Gordon-MIT Engineering Leadership Program.

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BIOGRAPHICAL INFORMATION

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