The CDIO Syllabus v2.0
An Updated Statement of Goals for Engineering Education

Edward F. Crawley
Massachusetts Institute of Technology
Cambridge, Massachusetts, USA

Johan Malmqvist
Chalmers University of Technology
Göteborg, Sweden

William A. Lucas
Massachusetts Institute of Technology
Cambridge, Massachusetts, USA

Doris R. Brodeur
Massachusetts Institute of Technology
Cambridge, Massachusetts, USA

ABSTRACT

Modern engineering education programs seek to impart to the students a broad base of knowledge, skills, and attitudes necessary to become successful young engineers. This array of abilities is represented in the CDIO Syllabus, an attempt to create a rational, complete, consistent, and generalizable set of goals for undergraduate engineering education. This paper examines the content and structure of the Syllabus, as well as the roles played by the Syllabus in the design and operation of educational programs.

The paper begins by examining the content and structure of the Syllabus, and then contrasts the Syllabus with other important taxonomies of educational outcomes. The CDIO Syllabus is first compared with the UNESCO Four Pillars of Learning, with which if is aligned at a high level. The Syllabus is then compared with national accreditation and evaluation standards of several nations. The finding is that the CDIO Syllabus is consistent and more detailed and comprehensive than any of the individual standards.

Based on these comparisons, as well as other input received over the last decade since the Syllabus was originally written in 2001, a revised and updated Syllabus is presented, in part to add missing skills and in part to clarify nomenclature and make the Syllabus more explicit and more consistent with national standards. The result is called the *CDIO Syllabus version 2.0.*

In modern society, engineers are increasingly expected to move to positions of leadership, and often take on an additional role as an entrepreneur. This paper also explores the degree to which the CDIO Syllabus already covers these topics, and the optional extension to the CDIO Syllabus that more adequately covers these two important roles of engineers.

KEYWORDS

CDIO Syllabus, knowledge taxonomies, ABET, CEAB, CDIO Standard 2, engineering leadership, entrepreneurship

INTRODUCTION

In contemporary undergraduate engineering education, there is a seemingly irreconcilable tension between two growing needs. On one hand, there is the ever-increasing body of technical knowledge that graduating students must command. On the other hand, there is a growing recognition that young engineers must possess a wide array of personal, interpersonal, and system building knowledge and skills that will allow them to function in real engineering teams and to produce real products and systems, meeting enterprise and societal needs.

Over the last decade, there has evolved a broad sense that there is a need to create a new vision and concept for undergraduate education. One approach to this, recognizable to engineering faculty, is to engage this problem by applying an *engineering problem solving paradigm*. This entailed first developing a comprehensive understanding of the skills needed by the contemporary engineer, and then designing and education to meet these requirements. Cast in just slightly different language, educators would begin with the development of educational objectives and learning outcomes, and then design aligned curriculum and assessment. In either framing of the problem, an early step is the development of comprehensive goals and outcomes.

Since 2000, we have been engaged in an organized international educational initiative centered on the CDIO approach, which is structured around 12 principles of effective practice [1]. The first and organizing principle is that the conceiving-designing-implementing-operating of products, processes and systems should be the authentic context of engineering education. [2] A learning context is the set of cultural surroundings and environments that contribute to understanding, and in which knowledge and skills are learned. The CDIO approach holds that the product, process, or system lifecycle (conceiving-designing-implementing-operating), should be the *context*, but not the *content*, of engineering education. The setting of the education, the skills we teach, and the attitudes we convey should all indicate that conceiving-designing-implementing-operating is the authentic role of engineers in their service to society.

A second principle of effective practice of the CDIO approach is that a program should set *"Specific, detailed learning outcomes for personal and interpersonal skills, and product, process, and system building skills, as well as disciplinary knowledge, consistent with program goals and validated by program stakeholders."* [1] In order to serve as a reference document for this process, the framework document entitled *CDIO Syllabus – A Statement of Goals for Undergraduate Engineering Education* was published in 2001. [3] The *CDIO Syllabus* was developed through discussions with focus groups comprised of various stakeholders, and by reference to other documentation of the time. As shown in Table 1, the CDIO Syllabus classified learning outcomes into four high-level categories: technical knowledge, personal and professional attributes, interpersonal skills, and the skills specific to the engineering profession. The content of each section was expanded in the CDIO Syllabus to a second level (also shown in Table 1), to a third level (see Appendix A), and to a fourth level (see Appendix B). This detailed version of the Syllabus was explicitly correlated with key documents listing engineering education requirements and desired attributes. As a result of this development process, the CDIO Syllabus emerged in 2001 as what we will now call the *CDIO Syllabus version 1.0*.

CDIO Syllabus v1.0 has proven to be a useful reference in over 100 programs worldwide for setting program goals, planning curricula, and evaluating student learning. It has been translated into Swedish, French, Spanish, Vietnamese and Chinese. Of course, the Syllabus is just a reference document, and it is not prescriptive. If programs feel that the Syllabus is not appropriate for their programs, or needs to be expanded, they can modify it in any way desirable to them.

The general objective of the CDIO Syllabus is to summarize formally a set of knowledge, skills and attitudes that alumni, industry and academia desire in a future generation of young engineers. The Syllabus can be used to define expected outcomes in terms of learning objectives of the personal, interpersonal and system building skills necessary for modern engineering practice. Further, the Syllabus can be used to design new educational initiatives, and it can be employed as the basis for a rigorous outcomes-based assessment process, such as that required by the Accreditation Board for Engineering Technology (ABET), and increasingly by other international accreditation processes as well.

The required skills of engineering are best defined through the examination of the practice of engineering for which we prepare our students. In fact, from its conception as a profession until the middle of the 20th century, engineering education was based on practice. With the advent, in the 1950s, of the engineering science-based approach to engineering education, the education of engineers became more distant from the practice of engineering. Engineering science became the dominant culture of engineering schools. Many universities are now moving to a new synthesis of engineering science and authentic practice.

Over the last 30 years, industry in the United States and elsewhere has made a concerted effort to signal their needs and support this transition. Yet, statements of high-level goals, written in part by those outside the academic community, have not made the kind of fundamental impact their authors desired. We examined this issue, and decided there were two root causes for this lack of convergence between engineering education and practice: an absence of rationale and an absence of detail.

Our approach was to reformulate the underlying need to make the rationale apparent. A statement of the underlying need for engineering education is that:

> *Graduating engineers should be able to*
> *conceive-design-implement-operate*
> *complex value-added engineering systems*
> *in a modern team-based environment.*

If we accept this conceive-design-implement-operate premise as the *context* of engineering education, we can then rationally derive more detailed goals for the education. The second barrier is the fact that the "lists" of desired attributes, as written, lack sufficient detail and specificity to be widely understood or implemented. Therefore, we composed the CDIO Syllabus to provide the necessary level of detail.

The specific objective of the CDIO Syllabus is to create a clear, complete, consistent, and generalizable set of goals for undergraduate engineering education, in sufficient detail that they can be understood and implemented by engineering faculty. These goals would form the basis for educational and learning outcomes, the design of curricula, as well as the basis for a comprehensive system of student learning assessment. In addition, they would form the basis for effective communication, benchmarking, inter-university sharing, and international correspondence.

Our goal was to create a taxonomy of engineering learning that is rationalized against the norms of contemporary engineering practice, comprehensive of all known other sources, and peer-reviewed by experts in the field. Further, we sought to develop a list that is prioritized, appropriate to university education, and in a form that can be expressed as learning objectives.

The objective of this paper is to review the CDIO Syllabus, ten years after its drafting, for its applicability and continued relevance. We have introduced some minor changes in the document to increase its contemporary relevance and broaden its coverage, and call this revised document the CDIO Syllabus v2.0. The modifications to the first and second level of the Syllabus are modest, as show in Table 2. The paper first reviews the high-level content and structure of the Syllabus. A discussion is then presented of use of the Syllabus in aligning curriculum, teaching and learning, and assessment. Then the historical development and recent updating of the more detailed Syllabus will be presented, culminating in the complete version 2.0 of the document. Finally, a proposed extension of the Syllabus to include entrepreneurship and leadership is discussed.

Table 1. CDIO Syllabus v1.0 at the Second Level of Detail

1 TECHNICAL KNOWLEDGE AND REASONING 1.1 KNOWLEDGE OF UNDERLYING SCIENCE 1.2 CORE ENGINEERING FUNDAMENTAL KNOWLEDGE 1.3 ADVANCED ENGINEERING FUNDAMENTAL KNOWLEDGE **2 PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES** 2.1 ENGINEERING REASONING AND PROBLEM SOLVING 2.2 EXPERIMENTATION AND KNOWLEDGE DISCOVERY 2.3 SYSTEM THINKING 2.4 PERSONAL SKILLS AND ATTITUDES 2.5 PROFESSIONAL SKILLS AND ATTITUDES	**3 INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION** 3.1 MULTI-DISCIPLINARY TEAMWORK 3.2 COMMUNICATIONS 3.3 COMMUNICATIONS IN FOREIGN LANGUAGES **4 CONCEIVING, DESIGNING, IMPLEMENTING, AND OPERATING SYSTEMS IN THE ENTERPRISE AND SOCIETAL CONTEXT** 4.1 EXTERNAL AND SOCIETAL CONTEXT 4.2 ENTERPRISE AND BUSINESS CONTEXT 4.3 CONCEIVING AND ENGINEERING SYSTEMS 4.4 DESIGNING 4.5 IMPLEMENTING 4.6 OPERATING

Table 2. CDIO Syllabus v2.0 at the Second Level of Detail
(Underlined Text is Updated from v1.0)

1 DISCIPLINARY KNOWLEDGE AND REASONING	**3 INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION**
1.1 KNOWLEDGE OF UNDERLYING MATHEMATICS AND SCIENCE	3.1 TEAMWORK
1.2 CORE FUNDAMENTAL KNOWLEDGE OF ENGINEERING	3.2 COMMUNICATIONS
1.3 ADVANCED ENGINEERING FUNDAMENTAL KNOWLEDGE, METHODS AND TOOLS	3.3 COMMUNICATIONS IN FOREIGN LANGUAGES
2 PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES	**4 CONCEIVING, DESIGNING, IMPLEMENTING, AND OPERATING SYSTEMS IN THE ENTERPRISE, SOCIETAL AND ENVIRONMENTAL CONTEXT**
2.1 ANALYTICAL REASONING AND PROBLEM SOLVING	4.1 EXTERNAL, SOCIETAL AND ENVIRONMENTAL CONTEXT
2.2 EXPERIMENTATION, INVESTIGATION AND KNOWLEDGE DISCOVERY	4.2 ENTERPRISE AND BUSINESS CONTEXT
2.3 SYSTEM THINKING	4.3 CONCEIVING, SYSTEMS ENGINEERING AND MANAGEMENT
2.4 ATTITUDES, THOUGH AND LEARNING	4.4 DESIGNING
2.5 ETHICS, EQUITY AND OTHER RESPONSIBILITIES	4.5 IMPLEMENTING
	4.6 OPERATING

FIRST- AND SECOND-LEVEL CONTENT OF THE CDIO SYLLABUS

First-Level Structure

In this section, we present the high-level content and structure of the CDIO Syllabus. The departure point for the derivation of the CDIO Syllabus' content is the simple statement that *engineers engineer*; that is, they build systems and products for the betterment of humanity. To enter the contemporary profession of engineering, students must be able to perform the essential function of an engineer which, as we have stated is that

> G*raduating engineers should be able to:*
> *conceive-design-implement-operate*
> *complex value-added engineering systems*
> *in a modern team-based environment.*

Stated another way, graduating engineers should appreciate the engineering *process*, be able to contribute to the development of engineering *products*, and do so while working in engineering *organizations*. Implicit is the additional expectation that engineering graduates should develop as whole, mature, thoughtful individuals.

These high-level expectations map directly to the first- or highest-level organization of the CDIO Syllabus. (see Table 2) Examining the mapping of the first level Syllabus items to these four expectations, we can see that a mature individual interested in technical endeavors possesses a set of *Personal and Professional Skills and Attributes*, which are central to the practice. In order to develop complex value-added engineering systems, students must have mastered the fundamentals of the appropriate *Disciplinary Knowledge and Reasoning*. To work in a modern team-based environment, students must have developed the *Interpersonal Skills* of teamwork and communications. Finally, to create and operate products and systems, a student must understand something of

Conceiving, Designing, Implementing, and Operating Systems in the Enterprise, Societal and Environmental Context. The four-section organization of the Syllabus reflects disciplinary knowledge, how to think, how to work with others, and how to engineer.

The first section, *Disciplinary Knowledge and Reasoning*, is program specific, that is, it outlines major disciplinary concepts of a specific engineering domain. Sections 2, 3, and 4 are more generic and applicable to virtually any engineering program. One could argue that this structure of Knowledge, Thinking and Acting, Working with Others, and Working Professionally is a taxonomy that can be applied to any field of study which prepares students for a profession. In fact, the CDIO Syllabus has been applied to other professional areas (e.g., business management) largely by customizing Sections 1 and 4, but leaving Sections 2 and 3 largely unchanged.

Second-Level Structure

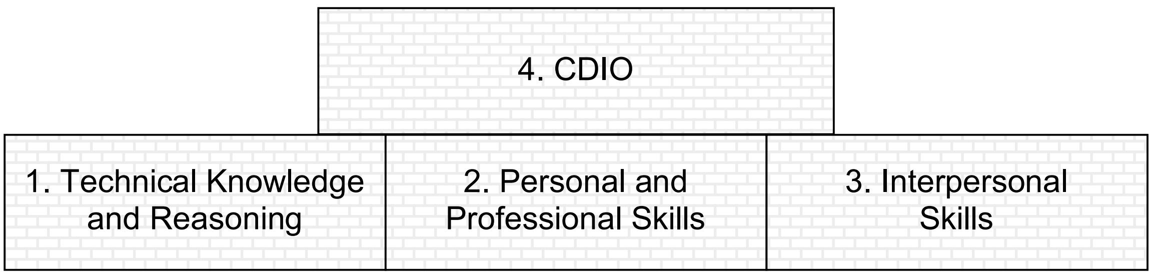

Figure 1: Building blocks of knowledge, skills, and attitudes necessary to Conceive, Design, Implement, and Operate Systems in the Enterprise, Societal and Environmental Context (CDIO).

The second level of the Syllabus consists of 17 sections, assigned to the four sections shown in Figure 1. These are roughly at the level of detail of national standards and accreditation criteria. Section 1 of CDIO Syllabus v2.0 is now called *Disciplinary Knowledge and Reasoning*. Modern engineering professions often rely on a necessary core Knowledge of Underlying Mathematics and Sciences (1.1). A body of Core Engineering Fundamental Knowledge (1.2) builds on that science core, and a set of Advanced Engineering Fundamental Knowledge, Methods and Tools (1.3) moves students towards the skills necessary to begin a professional career. This section of the CDIO Syllabus is, in fact, a placeholder for the more detailed description of the disciplinary fundamentals necessary for any particular engineering education. Section 1 details will vary in content from field to field.

In the remainder of the Syllabus, we have endeavored to include the knowledge, skills and attitudes that all engineering graduates might require. Section 2 begins with the three modes of thought most practiced professionally by engineers: Analytical Reasoning and Problem Solving (2.1), Experimentation, Investigation and Knowledge Discovery (2.2) and System Thinking (2.3). The detailed topical content of these sections at a third level is shown in Appendix A, and a fourth or implementable level is given in Appendix B. There is parallelism in these three sections (2.1 - 2.3). Each starts with a subsection which is essentially “formulating the issue,” moves through the particulars of that mode of thought, and ends with a section which is essentially “resolving the issue.”

Those personal values and attitudes that are used primarily in a professional context and that reflect on responsibilities are called Ethics, Equity and Other Responsibilities (2.5).

These include professional ethics, integrity and social responsibility, professional behavior, visioning for career and life, currency in engineering, equity and diversity and trust and loyalty. While these values and attitudes are applicable to engineering, there is nothing in this section that is conceptually particular to engineering. The subset of personal skills that are not primarily associated with responsibilities, are called Attitudes, Thought and Learning (2.4). These include the general character traits of initiative and perseverance, the more generic modes of thought of creative and critical thinking, and the skills of self-awareness and metacognition, curiosity and lifelong learning and educating, and time management.

Section 3 *Interpersonal Skills* is a distinct subset of the general class of personal skills, focused on interaction with others. They are divided into three overlapping sets called Teamwork (3.1) Communications (3.2), and Communications in Foreign Languages (3.3). Teamwork comprises forming, operating, growing and leading a team, as well as skills specific to technical and multidisciplinary teamwork. Communications comprises the skills necessary for formal communication: devising a communications strategy and structure; and those necessary to use the four common media -- written, oral, graphic and electronic. In addition, there is a set of informal communications and relational skills: inquiry and effective listening, negotiation, advocacy, and networking. Command of a foreign language is an important part of engineering in a globalized society. Because of its importance, English is called out specifically. Languages of regional commerce and industry are also important, for example, speaking both Spanish and Portuguese in South America. Command of additional languages is considered beneficial.

Section 4 *Conceiving, Designing, Implementing, and Operating Systems in the Enterprise, Societal and Environmental Context* presents a view of how product or system development moves through four metaphases, Conceiving (4.3), Designing (4.4), Implementing (4.5), and Operating (4.6). The chosen terms are descriptive of hardware, software and process industries. Conceiving runs from market or opportunity identification though high-level or conceptual design, and includes system engineering and development project management. Designing includes aspects of design process, as well as disciplinary, multidisciplinary, and multi-objective design. Implementing includes hardware and software processes, test and verification, as well as design and management of the implementation process. Operating covers a wide range of issues from designing and managing operations, through supporting product lifecycle and improvement, to end-of-life planning.

Products and systems are created and operated within an Enterprise and Business Context (4.2), and engineers must understand these sufficiently to operate effectively. The skills necessary to do this include recognizing the culture and strategy of an enterprise, and understanding how to act in an entrepreneurial way within an enterprise of any type or size. In addition, working effectively in international organizations, understanding new technology development and engineering project finance are skills which engineers will likely employ. Likewise, enterprises exist within a larger External, Societal and Environmental Context (4.1), an understanding of which includes such issues as the relationship between society and engineering, and requires a knowledge of the broader historical, cultural, contemporary and global context. Increasingly, understanding environmental context, and planning for sustainable development are necessary elements of context.

Comparison with the UNESCO and Other High-Level Frameworks

It its high-level organization, we have tried to organize the CDIO Syllabus in a rational manner. (see Table 2) The first level of Syllabus organization reflects an engineer who is a well-developed individual (Section 2), engaged in a process (Section 4), which is embedded in an organization (Section 3), with the intent of building products (Section 1). The 17 topics at the second level reflect much of the modern practice and scholarship on learning and the profession of engineering.

One of the most important aspects of the CDIO Syllabus is this choice of internal organization. A template for learning outcomes can be organized in many ways. For example, the 11 ABET accreditation criteria (criteria 3a – 3k) are not subdivided into categories at all. [4] The 2008 European EQF characteristics are categorized as Knowledge, Skills and Competences. [5] The 2008 EUR-ACE accreditation criteria are subdivided into Knowledge and Understanding, Engineering Analysis, Engineering Design, Investigations, Engineering Practice, and Transferable Skills.[6] The structure of domains of knowledge and skills (knowledge, personal skills, interpersonal skills and system building) was chosen as the organizing principle of the CDIO Syllabus.

An independent validation of this choice is the universal educational taxonomy developed by UNESCO [7]. They have proposed that all education should be organized around four fundamental types of learning:

- Learning to Know, that is, acquiring the instruments of understanding
- Learning to Do, so as to be able to act creatively on one's environment
- Learning to Live Together, so as to co-operate with other people
- Learning to Be, an essential progression that proceeds from the previous three

The organization of the CDIO Syllabus can be described as an adaptation of the UNESCO framework to the context of engineering education. At the first level, the CDIO Syllabus is divided into four categories:

1. *Technical Knowledge and Reasoning (or UNESCO Learning to Know)*
   Section 1 of the CDIO Syllabus defines the mathematical, scientific and technical knowledge that an engineering graduate should have developed.
2. *Personal and Professional Skills and Attributes (or UNESCO Learning to Be)*
   Section 2 of the Syllabus deals with individual skills, including problem solving, ability to think creatively, critically, and systemically, and professional ethics.
3. *Interpersonal Skills: Teamwork and Communication (or UNESCO Learning to Live Together)*
   Section 3 of the Syllabus lists skills that are needed in order to be able to work in groups and communicate effectively.
4. Conceiving, Designing, Implementing and Operating Systems in the Enterprise, Societal and Environmental Context (or *UNESCO* Learning to Do)
   Finally, Section 4 of the CDIO Syllabus is about what engineers do, that is, conceive-design-implement-operate products, processes and systems within an enterprise, societal, and environmental context.

Although the UNESCO framework precedes the first draft of the CDIO Syllabus by several years, the original drafters of the Syllabus did not know of its existence. Thus, UNESCO and CDIO independently arrived at the same fundamental structure of four pillars of learning.

Comparison with Engineering Professional Career Tracks
Another indicator of the rational structure of the Syllabus is the degree to which it maps to the needs of various career tracks that engineers follow as professionals. The Syllabus implicitly identifies a generic set of skills needed by all engineers, as well as more specific sets needed by different career tracks. The generic skills applicable to all tracks include: Analytical Reasoning and Problem Solving (2.1), System Thinking (2.3), Attitudes, Thought and Learning (2.4), Ethics, Equity and Responsibility (2.5), Teamwork (3.1), Communications (3.2), Communications in Foreign Languages (3.3) and External and Societal Context (4.1).

There are at least five different professional tracks that engineers follow, according to their individual talents and interests. The tracks and supporting sections of the Syllabus are:
1. The Researcher — Experimentation, Investigation and Knowledge Discovery (2.2)
2. The System Designer/Engineer — Conceiving, System Engineering and Management (4.3)
3. The Device Designer/Developer — Designing (4.4), Implementing (4.5)
4. The Product Support Engineer/Operator — Operating (4.6)
5. The Entrepreneurial Engineer/Manager — Enterprise and Business Context (4.2)

Of course, no graduating engineer will be expert in all of these potential tracks, and in fact may not be expert in any. However, the paradigm of modern engineering practice is that an individual's role will change and evolve. The graduating engineer must be able to interact in an informed way with individuals in each of these tracks, and must be educated as a generalist, prepared to follow a career that leads to any one or combination of these tracks.

It is important to note that the CDIO Syllabus exists at four levels of detail as shown in Appendix B. This decomposition is necessary to transition from the high-level goals (e.g., all engineers should be able to communicate) to the level of teachable and assessable skills (e.g., a topic in attribute 3.2.1, "analyze the audience"). This level of detail has many benefits for engineering faculty members, who in many cases are not experts in some of these topics. The detail allows instructors to gain insight into content and objectives, contemplate the deployment of these skills into a curriculum, and prepare lesson and assessment plans.

We have attempted to explain how the Syllabus forms a rational and generalizable basis for the goals of engineering education. Before discussing the Syllabus content in more detail, we briefly describe the use of the Syllabus in planning, executing and evaluating an educational program.

THE ROLE OF THE CDIO SYLLABUS IN EDUCATION

In the past ten years, the CDIO Syllabus has played a key role in the design of curriculum, teaching, and assessment in engineering education. As a formal statement of the intended learning outcomes of an engineering program, the Syllabus was able to
- Capture the expressed needs of program stakeholders
- Highlight the overall goals of an engineering program
- Provide a framework for benchmarking outcomes
- Serve as a template for writing program objectives and outcomes

- Provide a guide for the design of curriculum
- Suggest appropriate teaching and learning methods
- Provide the targets for student learning assessment
- Serve as a framework for overall program evaluation, and
- Communicate with faculty, students, and other stakeholders about the direction and purpose of a renewed engineering education that is centered on students and focused on outcomes.

In the curriculum and instructional design process, the CDIO Syllabus was adapted to diverse engineering programs in order to ensure that intended learning outcomes were aligned with institutional mission and vision, program objectives, and institutional and program values. (see Figure 2) This sometimes meant that a program omitted a few of the personal, interpersonal, and product, process, and system building skills found in the CDIO Syllabus, or added a few to highlight specific values of its institution.

The list of intended learning outcomes, adapted from the CDIO Syllabus, served as the basis for instructional decisions about curriculum, teaching and learning methods, and the assessment of student learning. In the curriculum design process at the program level, intended learning outcomes were detailed, sequenced from basic to complex, and mapped to appropriate levels and courses in the overall curriculum. For example, an intended learning outcome related to oral and written communication would be further defined into enabling steps and learning activities that would be integrated into courses at all levels of the curriculum so that by graduation, students would be able to demonstrate their competence in oral and written communication.

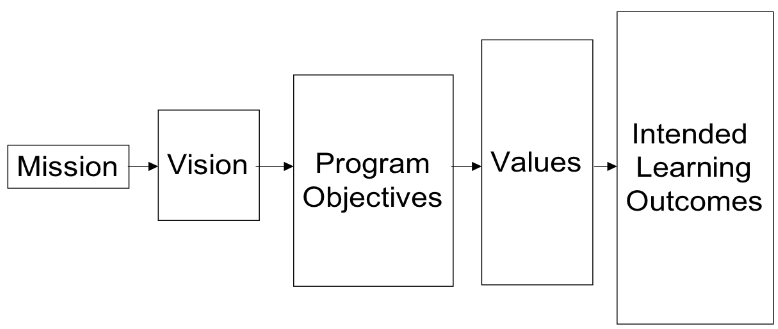

Figure 2. Alignment of intended learning outcomes with program mission

In the instructional design process at the course level, intended learning outcomes were used to guide decisions about appropriate teaching, learning, and assessment methods. The appropriateness of teaching and assessment methods depends on the nature and level of the learning outcomes. Using the same example of communication, appropriate teaching and assessment methods would be those that would allow students to practice their skills, get feedback on their performance, and in an assessment situation, demonstrate their achievements. Biggs refers to this purposeful relationship between the intended learning outcomes, teaching and learning activities, and assessment of student learning as *constructive alignment*. [8] (see Figure 3) Wiggins and McTighe refer to the outcomes, teaching and learning, and assessment sequence as *backward design*. [9] With or without a specific name, all models of instructional design highlight the centrality of learning outcomes and the importance of the alignment of curriculum, teaching, and assessment. The CDIO Syllabus was used as a starting point for defining these learning outcomes at the course level.

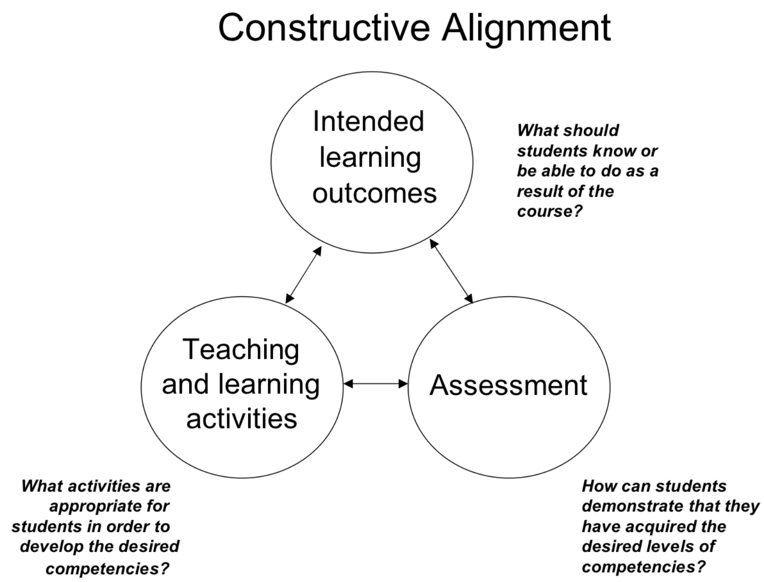

Figure 3. Alignment of intended learning outcomes with teaching and assessment

The CDIO Syllabus was also used in program evaluation and accreditation. For example, engineering programs at four different universities in the United States used the Syllabus as the framework for their self-studies for accreditation by ABET. [4] Using the language of ABET's EC2010, the CDIO Syllabus at the first level addressed ABET *Criterion 2 – Educational Objectives*. The topics of the Syllabus at the second level addressed ABET *Criterion 3 – Educational Outcomes*. Each topic was written as an educational outcome, in much the same language as ABET's required outcomes specified in Criteria 3a through 3k. These program learning outcomes subsequently became the starting point for writing learning outcomes for each course in the engineering curriculum.

ORIGIN AND EVOLUTION OF THE CDIO SYLLABUS

Developing Version 1.0 of the Syllabus

The CDIO Syllabus aims to be complete, consistent, and clear; that is, to describe the knowledge, skills, and attitudes expected of a graduating engineer in sufficient detail that curricula can be planned and implemented, and student learning assessed. While there is general agreement about the high-level view of these expectations among the comprehensive source documents cited [4,5,6,7], they lack the detail necessary to actually plan instruction and assess learning. We first present a brief review of the process used to arrive at the detailed content of the Syllabus a decade ago. The process blended elements of a product development user need study with techniques from educational research. The detailed content was derived through multiple steps, which included a combination of focus group discussions, document research, surveys, workshops and peer reviews.

Focus Groups
The first step in gathering the detailed content of the Syllabus was engaging four focus groups at MIT, including one of faculty, a group of current students, a group of industrial representatives, and a broadly based external review committee. To ensure applicability to all engineering fields, we included individuals with varied engineering backgrounds. The groups were presented with the question, “What, in detail, is the set of knowledge, skills and attitudes that a graduating engineer should possess?”

Document Review
A number of primary source documents were reviewed. The four principal ones were studied in the approximate chronological order of their appearance: the goals of the 1988 MIT Commission on Engineering Undergraduate Education, the ABET EC 2000 accreditation criteria [4], Boeing’s Desired Attributes of an Engineer [10], and the goals of the 1998 MIT Task Force on Student Life and Learning. These four sources were representative of the views of industry, government and academia on the expectations for a university graduate.

Draft Organization and Survey
We organized results of the focus groups, plus the topics extracted from the four principal source documents into a first draft, which contained the first multi-level organization of the content. This preliminary draft needed extensive review and validation. To obtain stakeholder feedback, a survey was conducted among four constituencies: faculty, senior industry leaders, young alumni (average age 25) and older alumni (average age 35). The qualitative comments from the roughly 100 respondents to this survey were incorporated, improving the Syllabus’ organization, clarity and coverage.

Workshops and Faculty Review
The first draft and survey comments were thoroughly reviewed in a faculty workshop at MIT and significantly reworked. This resulted in a second draft of the CDIO Syllabus, which was the first to have the four topics of the first-level organization (disciplinary knowledge, etc.), and contained 16 second-level sections (3 of which are placeholders in Section 1). These first- and second-level topics have been stable, with small changes, since 2000. The only second-level section subsequently added was 3.3 Communications in Foreign Languages. Using the information gathered from the focus groups, documents, surveys and workshops, the third level (Appendix A) and fourth level (Appendix B) of the Syllabus were developed.

Peer Review
The second draft of each of the 13 second-level topics in Sections 2 through 4 of the Syllabus was sent to disciplinary experts for review, that is, communications experts reviewed 3.1, design experts reviewed 4.4, etc. Through the expert reviews, we identified additional comprehensive source documents, as well as detailed references appropriate for each section. The peer reviewers also helped us to make the document more consistent with the organization of knowledge and terminology used by professionals in each of the fields. Combining the results of the peer review, and the check of additional comprehensive and detailed sectional references, we completed the third major draft of the Syllabus.

Collaborator review
In 2000, the CDIO Initiative was just beginning. Up to this point, the Syllabus had been under development at MIT. However, the final drafting of version 1.0 of the Syllabus became one of the first projects of the new collaboration. The Syllabus was reviewed from a European perspective, and, respectively, by mechanical, systems/IT, and transportation engineering faculty from Chalmers University of Technology, Linköping University, and the Royal Institute of Technology (KTH). This review surfaced many details that were specific to the U. S., to MIT, or to aerospace engineering. The outcome was a "translation" of the document into more generic form, with an attempt to find more universal terminology. Section 3.3, Communications in Foreign Languages, was also added at this time.

This multi-step process led to the publication of Version 1.0 of the CDIO Syllabus in 2001 [3].

Revising the Syllabus to Create Version 2.0

Since the CDIO Syllabus was first drafted more than ten years ago, it has been a remarkably stable document, serving programs in all domains of engineering in educational institutions of all types throughout the world. However, there have been pressures to change the Syllabus. These pressures have two primary sources. The first pressure arises from the development of new taxonomies of knowledge that surface new issues or organizations that should be considered. The second pressure comes from questions from users of the Syllabus looking for clarification or for knowledge and skill areas that seem to be missing. We review the correlation of the CDIO Syllabus with other documents, and then summarize the most frequently heard user concerns.

Comparison with ABET
The most common comparison documents for the CDIO Syllabus are those of national accreditation or evaluation bodies, usually produced by governments or professional societies. CDIO programs at different universities worldwide usually need to meet their respective national or accreditation standards, for example, ABET in the United States [4] or the National Agency for Higher Education in Sweden [11]. This need brings the correlation of the CDIO Syllabus with national outcomes requirements into focus. During the development of the first version of the CDIO Syllabus, it was correlated with the outcomes criteria of ABET EC2000. The updated Syllabus has been correlated with ABET EC2010. [4] The most relevant section of ABET EC2010 is Criterion 3 on *Program Outcomes and Assessment*. (Additions to the EC2000 criteria are underlined.)

> Engineering programs must demonstrate that their graduates have
>
> (a) an ability to apply knowledge of mathematics, science, and engineering
> (b) an ability to design and conduct experiments, as well as to analyze and interpret data
> (c) an ability to design a system, component, or process to meet desired needs <u>within realistic constraints, such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability</u>
> (d) an ability to function on multidisciplinary teams
> (e) an ability to identify, formulate, and solve engineering problems

(f) an understanding of professional and ethical responsibility
(g) an ability to communicate effectively
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, societal and environmental context
(i) a recognition of the need for, and an ability to engage in, life-long learning
(j) a knowledge of contemporary issues
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

The correlation of the CDIO Syllabus with ABET EC2010 Criterion 3 is shown in Figure 4. In general, the CDIO Syllabus reflects a more encompassing view of engineering than does ABET EC2010, by considering the full product/system/process lifecycle, including the implementing and operating life phases, whereas the ABET EC2010 criteria focus on the design phase. Overall, the CDIO Syllabus includes all of the ABET EC2010 criteria, but the reverse is not the case. The ABET criteria omit references to a wide array of skills and attitudes in Section 2.4 of the CDIO Syllabus, including creative and critical thinking, as well as the skill of communicating in foreign languages (3.3). However, the major advantage of the CDIO Syllabus is that it is more detailed, containing two or three more levels of detail than do the ABET EC2010 criteria. The increased levels of detail facilitate the interpretation of general statements, such as “communicate effectively”, that are common in national outcomes requirements.

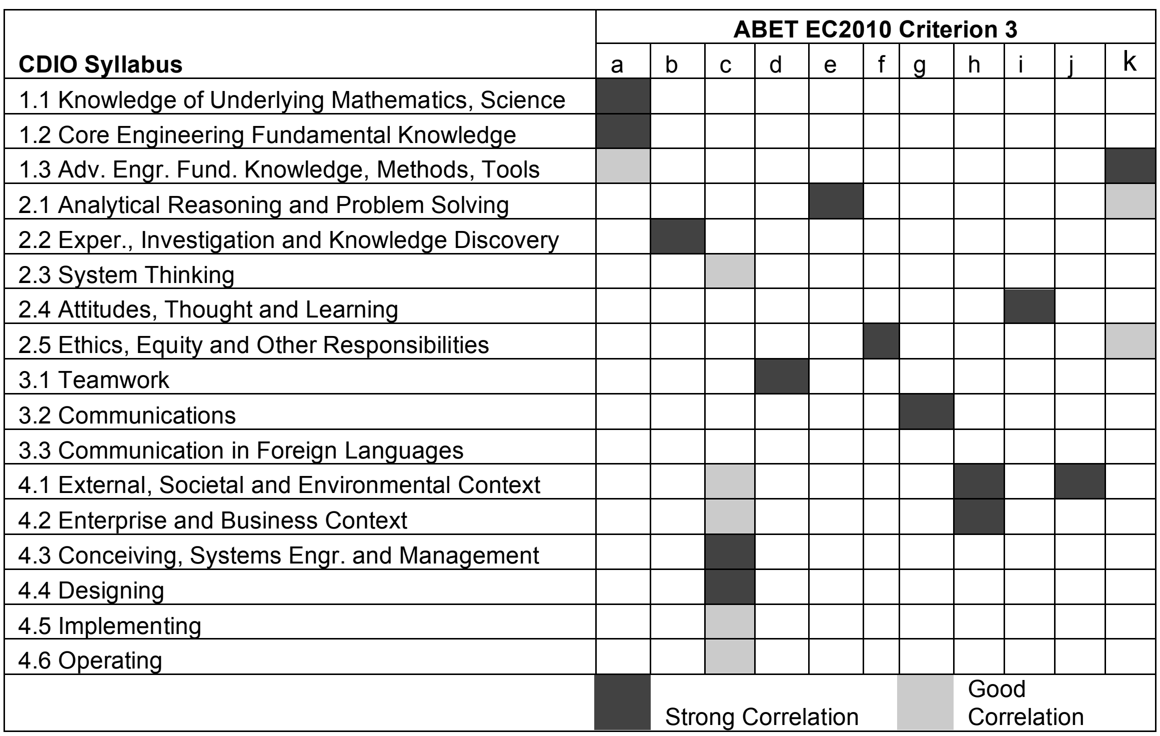

Figure 4. The CDIO Syllabus correlated with ABET EC2010 Criterion 3

Comparison with CEAB and other National Evaluation Documents
In September 2008, *Engineers Canada,* through its Canadian Engineering Accreditation Board (CEAB), published a new set of accreditation criteria and procedures.[12] The criteria include 12 graduate attributes that are well correlated with the CDIO Syllabus:

3.1.1. Knowledge Base for Engineering
3.1.2. Problem Analysis
3.1.3. Investigation
3.1.4. Design
3.1.5. Use of Engineering Tools
3.1.6. Individual and Team Work
3.1.7. Communication Skills
3.1.8. Professionalism
3.1.9. Impact of Engineering on Society and the Environment
3.1.10. Ethics and Equity
3.1.11. Economics and Project Management
3.1.12. Life-Long Learning

The correlation of the CDIO Syllabus with the CEAB criteria is illustrated in Figure 5 [13] Again, the CDIO Syllabus is more comprehensive than the national criteria, although the mapping between the two is good. The CDIO Syllabus at the third level of detail provides a more refined definition of the 12 graduate attributes specified in the new CEAB document, and can help institutions to meet these new criteria.

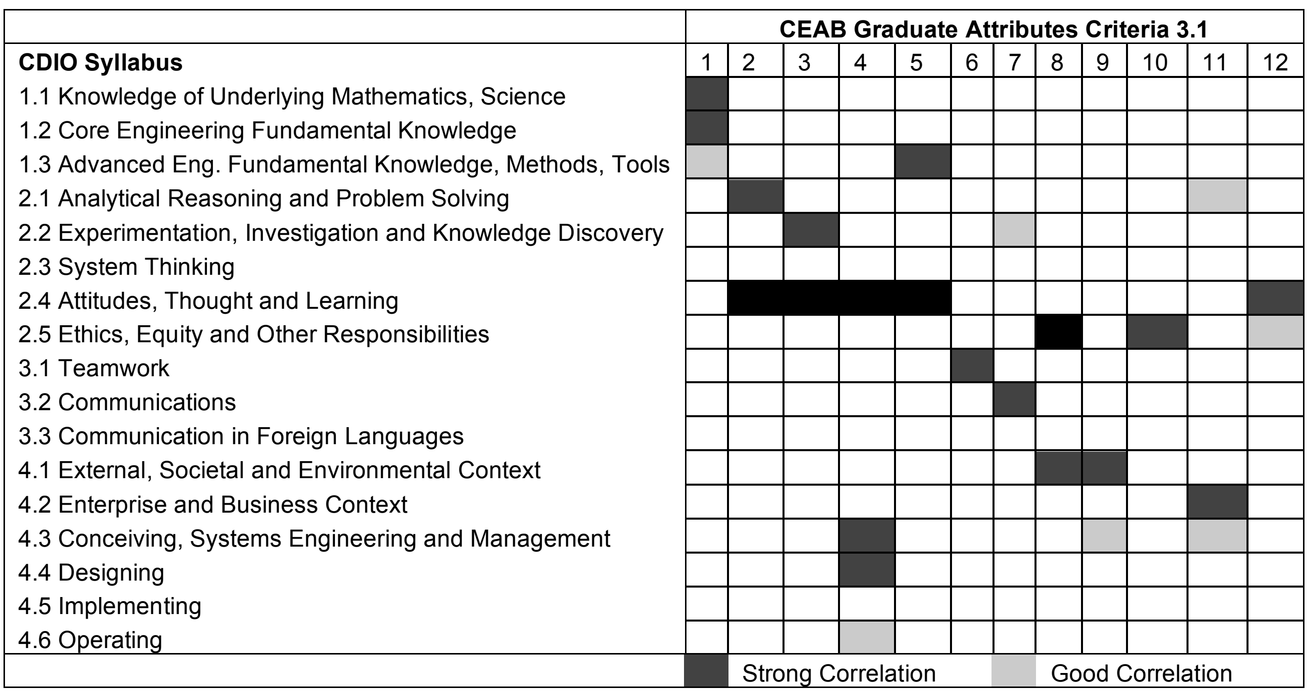

Figure 5. The CDIO Syllabus correlated with the CEAB Graduate Attributes

Subsequent analyses compared the CDIO Syllabus with national and international standards, such as the British UK-SPEC, the Dublin Descriptors, and the Swedish national engineering degree requirements [14], as well as the European EUR-ACE framework standards for accreditation of engineering programs [15]. Across all these comparisons, a similar pattern appears: The CDIO Syllabus states outcomes for engineering education that reflect a broader view of the engineering profession, and its greater levels of detail facilitate program and course development. A program whose design is based on the CDIO Syllabus will also satisfy its national requirements for specified program outcomes.

The principal modifications in the CDIO Syllabus that were identified by detailed comparisons with national accreditation and evaluation documents were primarily the clarification of some of the topics so that the correspondence is more explicit. The following changes were made in version 2.0 of the Syllabus: (see Appendix A and Appendix B)

- 1.0 -- Change to *Disciplinary Knowledge and Reasoning* (Swedish Ordinance and EUR-ACE)
- 1.1 -- Add *Mathematics* (ABET)
- 1.3 -- Add *Methods and Tools* (ABET and CEAB)
- 2.1 -- Change to *Analytical Reasoning and Problem Solving* (ABET and CEAB)
- 2.2 -- Add *Investigation* to the title (CEAB)
- 2.5.1 -- Change to *Ethics, Integrity, and Social Responsibility* (ABET and CEAB)
- 2.5.5 – Add *Equity and Diversity* (CEAB)
- 3.1.5 -- Add *Multidisciplinary Teaming* (ABET and CEAB)
- 3.2.7 -- Add *Inquiry, Listening and Dialogue* (CEAB)
- 4.2.7 -- Add *Engineering Project Finance and Economics* (CEAB and UK-SPEC)
- 4.3.1 -- Add *Understanding Needs* (ABET and CEAB)
- 4.3.3 -- Add *Systems Engineering* (CEAB)
- 4.4.6 – Modify to indicate *safety* (CEAB)

Modifications Based on User Feedback

Innovation and Invention

In the last decade, the concept of innovation as a role or purpose of engineering has become commonly accepted. However, there are several different understandings of the word *innovation*. The broader one is the development and exploitation of new ideas. A more specific understanding applicable to engineering is that *innovation* is the development and introduction into the market of new goods and services. If one accepts this latter definition, innovation is just the market-oriented view of what the CDIO Syllabus defines in Sections 4.2 through 4.6 – Conceiving, System Engineering and Management, Designing, Implementing, and Operating, within an enterprise. More emphasis may need to be placed on understanding the market and user needs as a basis for developing goals, but otherwise, the skills and knowledge necessary to foster this more specific use of innovation is included in the CDIO Syllabus. *Invention* refers to the development of new technologies that may enable innovations, including their incorporation into products and services that will be delivered. While invention is present in the CDIO Syllabus, it is made explicit only at the fourth level of detail. It was necessary to raise the visibility of this important engineering function.

With respect to innovation and invention, the following modifications to the CDIO Syllabus are incorporated into version 2.0: (see Appendix A and Appendix B)

- 4 -- Add *Innovation* to the title
- 4.2.2 -- Change to *Enterprise Stakeholders, Strategy and Goals*
- 4.2.6 -- Add *New Technology Development and Assessment*
- 4.2.7 -- Add *Engineering Project Finance and Economics*

- 4.3.1 -- Change to *Understanding Needs and Setting Goals*

Sustainability

During the last decade, the importance of sustainable development has become widely recognized. Future engineers need to be able to mitigate the negative environmental consequences of current energy and production systems, and create new ones that are essentially carbon neutral. It follows that engineering education must emphasize sustainability principles. In this context, the CDIO Syllabus, v1.0, had received some criticism, as sustainability is mentioned in only one place, at the fourth level of detail, under 4.4.6. The low visibility has been interpreted as insufficient emphasis on this topic.

However, it could also be argued that CDIO is fundamentally aligned with the ideas of sustainability: Engineers are said to conceive, design, implement and operate complex technical systems with the entire product/process/system lifecycle in mind. Moreover, sustainability is a complex concept. It includes three main dimensions: economic, environmental, and social sustainability, including both subject matter and judgmental aspects, such as, ethics and decision-making [16]. There are many places in the CDIO Syllabus that emphasize the lifecycle perspective, for example, requirements should cover all phases of the lifecycle; analyses should be made of lifecycle values and costs; and product retirement should be planned ahead. With this broader perspective in mind, links between sustainability principles and CDIO Syllabus topics were identified [17]. In essence, we concluded that the CDIO Syllabus does support the development of an engineering education that strongly considers sustainability. Nevertheless, the visibility of the concept of sustainability needed to be strengthened in the CDIO Syllabus, signaling its importance to students, industry, and program and course developers.

Based on these issues of *sustainability*, the following modifications to the CDIO Syllabus are incorporated into version 2.0: (see Appendix A and Appendix B)

- 4 -- Include *Environmental*
- 4.1 -- Include *Environmental*
- 4.1.7 -- Add *Sustainability and the Need for Sustainable Development*
- 4.4.6 -- Make *Design for Sustainability* more explicit
- 4.5.1 -- Change to *Designing a Sustainable Implementation Process*
- 4.6.1 -- Change to *Designing and Optimizing Sustainable and Safe Operations*

Internationalization and Mobility

Engineers increasingly work with international partners at a site, in multinational companies, and with companies, suppliers or markets in different lands. The engineering workforce itself is more mobile, and it is not uncommon for engineers to work in nations other than the one in which they received their training. In order to prepare students for this future, there were several subtle but meaningful changes made to the Syllabus:

- 4.1.6 – Add *Developing a Global Perspective*
- 4.2.5 -- Add *Working in International Organizations*

The Syllabus already had several sections pertinent to internationalization, including 3.3 Communications in Foreign Languages and reference in 2.5.2 to international norms. The two new topics work in concert with other aspects of the Syllabus to prepare a student for mobility and international efforts.

Other Critiques and Inputs

Over the years, several universities have observed that the CDIO Syllabus does not place sufficient emphasis on the topics of ethics, morality, and social responsibility. For example, two universities in Chile adapted the CDIO Syllabus to their programs by adding to 2.4 the following (translated from the Spanish): *Commitment to Christian principles; Concern for those in great need*; and *Concern for the environment.* In response to this criticism, Section 2.5 was renamed as *Ethics, Equity and Other Responsibilities*, and 2.5.5 *Equity and Diversity* and 2.5.6 *Trust and Loyalty* were added.

Others have observed that, while the CDIO Syllabus covers aspects of formal communication well, that is, writing, oral presentations, and graphics, it could be more explicit about informal and interpersonal communications. This led to the inclusion of several new topics in Section 3.2, including:

- 3.2.7 – Add *Inquiry, Listening and Dialog*
- *3.2.8* – Add *Negotiation, Compromise and Conflict Resolution*
- 3.2.9 – Add *Advocacy*
- 3.2.10 – Add *Establishing Diverse Connections and Networking*

Another important critique is based on the work of Johan DeGraeve, which proposes a *Five-E Model* for engineering education. The model, developed at Group T International University College in Leuven, Belgium, describes five "*E*" terms around which their program of educating *integral engineers* is built. [18] The first three *E*'s represent the roles engineers play in society.

1. *ENGINEERING* -- making things
   Integral engineers create by making use of technology and the underlying sciences. They are familiar with a multidisciplinary approach.
2. *ENTERPRISING* -- getting things done
   Integral engineers have vision. On this basis, they define a mission around which they gather others. Through innovation, daring and leadership they effectively get things done.
3. *EDUCATING* -- developing oneself and others
   Integral engineers are capable of coaching themselves, others, and teams. Their ideal is the development of each and everyone.
4. *ENVIRONMENTING* -- embracing all elements
   Integral engineers are conscious of the influence of technology on the world, and vice versa. This is why they take into account the impact of their actions on ethics, ecology, aesthetics and economics within a globalizing and ever-evolving world.
5. *ENSEMBLING* -- transcending and including
   Integral engineers see the coherence of things. By differentiating and integrating, and approaching all things from different angles, they achieve deeper insights and arrive at ever-richer experiences.

Based on a review of this document, the following minor changes were made to the Syllabus in version 2.0:

- 2.4.5 -- Add *Knowledge Integration (Ensembling)*
- 2.4.6 -- *Educating* was added

While helpful in rounding out the Syllabus, these modest changes do not necessarly capture the full scope of DeGraeve's vision of engineering education.

The net result of this process of comparison with national accreditation and evaluation document, user and other feedback is the revised version 2.0 of the CDIO Syllabus, found in Appendix A and Appendix B.

LEADERSHIP AND ENTREPRENEURSHIP

In modern society, engineers are increasingly expected to move to positions of leadership and to take on additional roles as entrepreneurs. Leadership is not necessarily positional, that is, a leader need not be a boss, manager, director or president. *Leadership* refers to the role of helping to organize effort, create vision, and facilitate the work of others. In the context of engineering, senior engineers are the ones who most often lead. *Entrepreneurship* in this context refers to the specific activity of creating and leading a new enterprise. Many, but not all, new enterprises are built around a product or technology, and involve entrepreneurial engineers. In this section, we explore the degree to which *leadership* and *entrepreneurship* are already included in the CDIO Syllabus v2.0, and the extensions that are necessary to more adequately address these two important roles of engineers.

Engineering leadership and entrepreneurship are not orthogonal to the skills already contained in the CDIO Syllabus. After all, the goal of the CDIO approach is "To educate students who are able to:

- Master a deeper working knowledge of technical fundamentals
- <u>*Lead*</u> in the creation and operation of new products, processes, and systems…" [1]

The knowledge, skills, and attitudes needed in the creation and operation of new products, processes, and systems should, therefore, already be contained in the CDIO Syllabus. In fact, there is a broad overlap, both between leadership and entrepreneurship, and between the two of them and the skills already in the Syllabus. To a certain extent, the three are just different profiles of the same broader set of skills, as suggested in Figure 6. This Venn diagram suggests the organization of the discussion that follows. We have already reviewed the CDIO Syllabus v2.0. Here, we discuss what could be added to expand the topics in the Syllabus beyond the already proposed modifications, to include *Engineering Leadership*. Finally, we examine what other topics are needed to embrace *Entrepreneurship.*

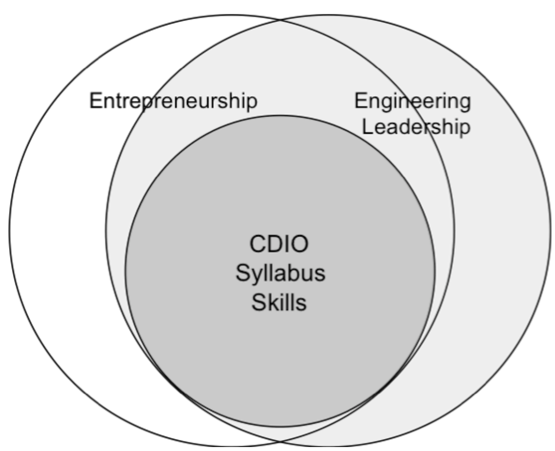

Figure 5. The overlapping relationship between the knowledge, skills and attitudes in the CDIO Syllabus, engineering leadership, and entrepreneurship

We recognize that many programs that use the CDIO Syllabus do not address leadership and entrepreneurship in their programs. For this reason, we have created an extension of the CDIO Syllabus for Leadership and Entrepreneurship, with the additional content discussed below. (see Appendix A and Appendix B)

The Expansion of the CDIO Syllabus to Include Engineering Leadership

Some, if not all, engineers will move, at some point in their careers, to positions of technical or engineering leadership, ranging from being a leader of a small team, to being the technical leader of an entire enterprise. Leadership is explicitly discussed in Section 3.1.4 of the CDIO Syllabus, but this topic discusses the skills needed in leading small groups, and is only a placeholder for the wider set of skills that an engineering leader is required to have. These skills include character traits, such as loyalty and integrity, and abilities, such as the ability to make sense of complex contextual information, to relate and persuade, to create transformational visions, and to deliver on those visions. In this section, we discuss relevant contemporary models of leadership, and propose extensions to the CDIO Syllabus.

Leadership Models
Much has been written over the years about the qualities of a leader. In contemporary scholarship, organizational leadership is closely studied by those in organizational behavior groups, often at schools of business or management. Diverse fields, including business, government, and the military have adopted these organizational models, and customized them to their respective domains. Generic models of leadership, then, can be customized for engineering contexts.

Among the many views of leadership development, the general approaches that may best fit engineering contexts are those that function in environments of change, uncertainty, and the deliberate pursuit of invention. [19] One school of thought that stands out is *Transformational Leadership* because of its emphasis on a driving need to change and to mobilize resources in new ways, requiring new visions of the future. [20] This model resonates with leaders of groups that use applied science and engineering to generate new products that may require redefining markets and business models.

Contingency theory reminds leaders that over time no single approach to leadership will fit all situations, and one must continually assess one's environment to provide appropriate leadership. [21] This approach thus incorporates the importance of providing vision and strong direction in one circumstance, and also recognizes when one might lead best by creating a stable and supportive environment in which others might lead. This view suggests that engineering leadership in a change-driven environment is situational. [22] The complex and specialized nature of engineering requires that leadership be found everywhere. There are instances when one must be able to listen to the technician on the shop floor who might be the first to see the solution to a design-for-production problem. In advancing technical fields, the individuals looking outward from the company at new technologies, and those working in an organization's laboratories, provide a kind of technology leadership. Others who follow markets, and observe novel uses of products that are enhancing or eroding markets, must exert a kind of situational leadership as well. All of these leaders need first to recognize that change is occurring, to make sense of what they are seeing and to communicate effectively with others.

The Four Capabilities Leadership Framework

The *Four Capabilities Leadership Framework,* developed at the Sloan School of Management at MIT, provides a scheme that organizes key leadership concepts as a foundation for engineering leadership education. [23] It begins with four assumptions: that leadership is distributed; that it is personal; that it continues to develop throughout one's career, and thus changes over time; and that each individual invents his/her own framework for how he/she will lead. The central skills are

1. *Sensemaking* -- making sense of the context of the changing world around us, including the use of small experiments to test and gain information
2. *Relating* -- developing trusted relationships with diverse individuals, using inquiry to know how to communicate effectively. and leadership through advocacy, even if one is not a formal leader
3. *Visioning* -- both to create a vision for oneself and to convey that vision to others
4. *Realizing the Vision* (*Inventing*) -- takes on a more complex meaning for engineers. Engineering leaders, like other leaders, need to invent ways to think through situations, and create ways of organizing their work with others. For engineers, the tasks of organizing work are central to their profession. This organization may involve establishing design teams, designing, setting up production and implementation, establishing who will do testing and by what means, operating, and a host of other activities.

The Bernard M. Gordon – MIT Engineering Leadership Program adapted this generic model of leadership to the context of engineering. Two sets of skills were added to the MIT Sloan Four Capabilities Model. The first set includes issues of leadership that have to do with attitudes and character, for example, initiative, the will to deliver, resourcefulness, integrity, and loyalty. The second set concentrates on a firm foundation of engineering knowledge and skills. The customized leadership model has six central skills:

1. The Attitudes of Leadership - Core Personal Values and Character
2. Relating to Others
3. Making Sense of the Context
4. Creating a Purposeful Vision
5. Realizing the Vision
6. Technical Knowledge and Critical Reasoning

Information about the *Gordon-MIT Engineering Leadership Program* can be found at http://web.mit.edu/gordonelp.

Comparing the structure of the *Gordon-MIT Engineering Leadership Program Capabilities of an Engineering Leader* with the CDIO Syllabus reveals a great deal of overlap. Version 2.0 of the Syllabus captures virtually all of the ideas contained in the first three sections of the *Capabilities of an Engineering Leader,* namely:

- **Attitudes of Leadership – Core Personal Values and Character,** including topics in Attitudes, Thought and Learning (2.4), and in Ethics, Equity and Other Responsibilities (2.5)
- **Relating to Others**, including topics in Teamwork (3.1), Communications (3.2) and potentially Communications in Foreign Languages (3.3)
- **Making Sense of Context**, including topics in External, Societal and Environmental Context (4.1), Enterprise and Business Context (4.2) Conceiving, Systems Engineering and Management (4.3) and System Thinking (2.3)

In addition, a new section 4.7 *Leading Engineering Endeavors* has been added to the Extended Syllabus v2.0. This new section defines the remaining topics in *Creating a Purposeful Vision* (4.7.1 to 4.7.4) and *Realizing the Vision* (4.7.5 to 4.7.10). (see Appendix A and Appendix B)

Creating a Purposeful Vision
- 4.7.1 – *Identifying the Issue, Problem or Paradox* (expands 4.3.1)
- 4.7.2 -- *Thinking Creatively and Imagining Possibilities* (expands 2.4.3)
- 4.7.3 -- *Defining the Solution* (expands 4.3.1)
- 4.7.4 -- *Creating New Solution Concepts* (expands 4.3.2 and 4.3.3)

Realizing the Vision
- 4.7.5 -- *Building and Leading an Organization and an Extended Organization* (builds on 4.2.4 and 4.2.5)
- 4.7.6 -- *Planning and Managing a Project to Completion* (builds on 4.3.4)
- 4.7.7 -- *Exercising Project/Solution Judgment and Critical Reasoning* (builds on 2.3.4 and 2.4.4)
- 4.7.8 -- *Innovation* – the conception, design and introduction of new goods and services (the leadership of 4.3 and 4.4)
- 4.7.9 -- *Invention* – the development of new devices, materials or processes that enable new goods and services (expands 4.2.6)
- 4.7.10 -- *Implementation and Operation* – the creation and operation of the goods and services that will deliver value (the leadership of 4.5 and 4.6)

The Expansion of the CDIO Syllabus to Include Entrepreneurship

Successful engineering entrepreneurship consists of engineering, plus engineering leadership, plus specific domain knowledge associated with business formulation and start-ups. As illustrated in Figure 6, we now define the knowledge and skills necessary for *Entrepreneurship*, over and above those described in the baseline CDIO Syllabus, v. 2.0, with the extension for engineering *Leadership*. Again, we examine appropriate models of entrepreneurship on which to base the discussion.

In the view of classical economics, *entrepreneurship* involves the redirection and mobilization of capital and human resources to form a new economic activity. This perspective considers any major innovation in an established firm to be entrepreneurship if it involves a novel economic activity that departs from the firm's prior business model, and accepts the risks of placing substantial investments in new products and creating new markets that did not previously exist. Today, the term *entrepreneurship* generally refers exclusively to starting a new company, while launching a radically new line of business is sometimes called *intrapreneurship,* or more simply *innovation* (as was discussed in a previous section). [24]

Engineering education should prepare students for both forms of entrepreneurship, which are more easily accommodated than intrapreneurship. In many instances, science- and technology-based discovery and invention in established companies may not require business innovation because often they do not require changes in markets. When engineering is a major component of a product that is intended to disrupt existing markets, much more care is needed in the design process, and the engineer needs to understand the trade-offs between product novelty and importance of time to market, product margins and hurdle rates needed to justify company investment, and other business considerations that influence design and implementation strategies. These issues are well addressed in the product development literature and can be included without difficulty in any engineer's education. In the context of the CDIO Syllabus, these aspects of learning would be largely addressed by the modifications discussed with respect to innovation.

Preparation for entrepreneurship, that is, the start of a new company, involves unique competencies. There are analogues, such as the similarity between recognizing new opportunities enabled by advancing technology, or writing business plans for either a new product line or a new company. However, there is an array of skills that engineers in an established company might never face, such as finding and hiring an entire company of talented professionals willing to accept risk, using equity to motivate innovation, or creating a new company culture where none existed.

In order to capture these additional skills of entrepreneurship, Section 4.8 was added to the Extended Syllabus v2.0. This new section includes the following topics: (see Appendix A and Appendix B)

- 4.8.1 -- *Company Founding, Formulation, Leadership and Organization*
- 4.8.2 – *Business Plan Development*
- 4.8.3 -- *Company Capitalization and Finances*
- 4.8.4 -- *Innovative Product Marketing*
- 4.8.5 -- *Conceiving Products and Services Around New Technologies*
- 4.8.6 – *The Innovation System, Networks, Infrastructure, and Services*
- 4.8.7 -- *Building the Team and Initiating Engineering Processes* (conceiving, designing, implementing and operating)
- 4.8.8 -- *Managing Intellectual Property*

SUMMARY

This paper has presented the following key concepts:

- The CDIO Syllabus was designed to be a rational, detailed, and relatively complete taxonomy for the knowledge, skills, and attitudes that graduating engineers should possess; and, it has been stable for almost ten years
- Its high-level structure was shown to be consistent with the Four Pillars of Learning outlined by UNESCO
- The Syllabus was instrumental in the design of constructively aligned learning outcomes, curricula, teaching approaches, student learning assessment, and program evaluation, and was found to be an effective way in which faculty communicate and benchmark their practice
- The CDIO Syllabus showed very good alignment with other outcomes-based taxonomies developed by national accreditation and evaluation bodies, and in many cases, was found to be more comprehensive and more detailed
- Based on comparisons with other taxonomies, and the frequent user questions raised over the years, particularly concerning innovation, invention, internationalization and sustainability, modifications in content and in labeling have been incorporated into Version 2.0 of the CDIO Syllabus
- In order to meet the needs of programs that explicitly address engineering leadership and entrepreneurship, an optional extension to the CDIO Syllabus has been developed

Benefits of the CDIO Syllabus were shown to apply to individual faculty, students, the engineering world, and the larger academic community.

- The detail in the CDIO Syllabus allowed individual faculty to gain detailed insight into its content and objectives, contemplate the deployment of these skills into a curriculum, and prepare teaching and assessment plans
- Adopting and disseminating the CDIO Syllabus facilitated comprehensive and rigorous education in its topics that benefited
    - students who enter engineering practice or research
    - industry that will reap the rewards of new engineers prepared to take the reigns of leadership, and
    - humankind who will enjoy improvement to the quality of life that comes with better products and services
- Widespread adoption of the CDIO Syllabus also facilitated the sharing of best curricular and pedagogic approaches, and promoted the development of standardized assessment tools, which resulted in better outcomes-based assessment.

REFERENCES

[1] Crawley, E. F., Malmqvist, J., Östlund, S., and Brodeur, D. R., *Rethinking Engineering Education: The CDIO Approach*, Springer-Verlag, New York, 2007.

[2] Crawley, E. F., Cha Jianzhong, Malmqvist, J., and Brodeur, D.R., "The Context of Engineering Education", *Proceedings of the 4th International CDIO Conference,* Hogeschool Gent, Gent, Belgium, June 16-19, 2008.

[3] Crawley, E. F., *The CDIO Syllabus: A Statement of Goals for Undergraduate Engineering Education*, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, 2001. Available at http://www.cdio.org. Accessed June 15, 2011.

[4] Accreditation Board of Engineering and Technology, *Criteria for Accrediting Engineering Programs: Effective for Evaluations during the 2010-2012 Accreditation Cycle*, 2010. Available at http://www.abet.org. Accessed June 15, 2011.

[5] European Commission: DG Education and Culture, *The European Qualification Framework for Lifelong Learning (EQF)*, Office for Official Publications of the European Communities, Luxemburg, 2008.

[6] ENAEE (European Network for Accreditation of Engineering Education), *EUR-ACE Framework Standards for the Accreditation of Engineering Programmes,* 2008. Available at http://www.enaee.eu/the-eur-ace-system/eur-ace-framework-standards/. Accessed June 15, 2011.

[7] Delors, J., et al., *Learning – the Treasure Within: Report to UNESCO of the International Commission on Education for the Twenty-First Century*, UNESCO Publishing, Paris, France, 1996.

[8] Biggs, J., *Teaching for Quality Learning At University, 2nd ed.*, The Society for Research into Higher Education and Open University Press, Berkshire: England, 2003.

[9] Wiggins, G., and McTighe, J., *Understanding by Design*, exp. 2nd ed., Prentice-Hall, Upper Saddle River, New Jersey, 2005.

[10] The Boeing Company, "Desired Attributes of an Engineer: Participation with Universities", 1996. Available at http://www.boeing.com/educationrelations/attributes.html. Accessed June 15, 2011.

[11] Högskoleverket, *Utvärdering av utbildningar till civilingenjör vid svenska universitet och högskolor – fulltextversion (Evaluation of "Civilingenjör" Degree Programs at Swedish Universities),* Rapport 2006:8 R, Högskoleverket, Stockholm, Sweden, 2006.

[12] Canadian Engineering Accreditation Board (CEAB), *Accreditation Criteria and Procedures*, 2010. Available at http://www.engineerscanada.ca/e/pu_ab.cfm. Accessed June 15, 2011.

[13] Cloutier, G., Hugo, R., and Sellens, R., "Mapping the Relationship Between the CDIO Syllabus and the CEAB Graduate Attributes: An Update", Proceedings of the 7th International CDIO Conference, Technical University of Denmark, Copenhagen, June 20-23, 2011.

[14] Malmqvist, J., *Relation between the Dublin Descriptors and Program Goal Statements based on the CDIO Syllabus*, Technical Report, Chalmers University of Technology, Göteborg, 2006.

[15] Malmqvist, J., "A Comparison of the CDIO and EUR-ACE Quality Assurance Systems", *Proceedings of the 5th International CDIO Conference*, Singapore Polytechnic, Singapore, 2009.

[16] The World Commission on Environment and Development (WCED), *Our Common Future*. Oxford University Press, Oxford, UK. 1987.

[17] Knutson Wedel, M., Malmqvist, J., Arehag, M., Svanström, M. "Implementing Engineering Education for Environmental Sustainability into CDIO Programs", *Proceedings of the 4th International CDIO Conference,* Gent, Belgium, 2008.

[18] Group T, Leuven, Belgium, *Key Terms: The Five E's*. Available at http://www.groupt.be/www/bachelor_programs/vision_of_engineering/key-terms-the-5-es. Accessed June 15, 2011.

[19] Boynton, A., and Fischer, B., *Virtuoso Teams: Lessons From Teams That Changed Their Worlds*, Prentice-Hall, New York, 2005.

[20] Bass, B. M., *Transformational Leadership*, Lawrence Erlbaum, London, 1998.

[21] Northouse, P. G., *Leadership: Theory and Practice, 4th ed.*, Sage Publications, Thousand Oaks, California, 2007.

[22] Burton, R. M., Eriksen, B., and Hakonsson, D. D., *Organizational Design: The Evolving State of the Art*, Springer, New York, 2006.

[23] Ancona, D., *Leadership in the Age of Uncertainty*. Available at http://mitleadership.mit.edu/pdf/LeadershipinanAgeofUncertainty-researchbrief.pdf. Accessed June 15, 2011.

[24] Menzel, H. C., Aaltio, I., and Aaltio, U., "On the Way to Creativity: Engineering as Intrapreneurship in Organizations", *Technovation, 27*, 2007, 732-743.

BIOGRAPHICAL INFORMATION

Edward F. Crawley is Ford Professor of Engineering, and Professor of Aeronautics and Astronautics and of Engineering Systems at MIT. He is Co-Director of the CDIO Initiative, and co-authored *Rethinking Engineering Education: The CDIO Approach*. He currently directs the MIT-Bernard M. Gordon Engineering Leadership Program, and can be reached at crawley@mit.edu.

Johan Malmqvist is Professor in Product Development and Dean of Education at Chalmers University of Technology, Göteborg, Sweden. He is Co-Director of the CDIO Initiative, and co-authored *Rethinking Engineering Education: The CDIO Approach*. His current research focuses on information management in the product development process (PLM), development of product-service systems, and curriculum development methodology. He can be reached at johan.malmqvist@chalmers.se.

William A. Lucas is Director of Research for the MIT-Bernard M. Gordon Engineering Leadership Program. He conducts research on the role of self-efficacy and intention in engineering and entrepreneurship education, and has assessed numerous educational programs in the United States and the United Kingdom. He can be reached at walucas@mit.edu.

Doris R. Brodeur is Professor of Education, serving as an Assessment and Evaluation Specialist at MIT. She co-authored *Rethinking Engineering Education: The CDIO Approach*, and designs and conducts workshops on the CDIO approach. She can be reached at dbrodeur@mit.edu.

Corresponding Author
Dr. Edward F. Crawley
Massachusetts Institute of Technology
77 Massachusetts Avenue – 33-402
Cambridge, MA 02139
1-617-253-3251
crawley@mit.edu

APPENDIX A

CONDENSED CDIO SYLLABUS v2.0
JUNE 2011

1 DISCIPLINARY KNOWLEDGE AND REASONING

1.1 KNOWLEDGE OF UNDERLYING MATHEMATICS AND SCIENCES
1.2 CORE ENGINEERING FUNDAMENTAL KNOWLEDGE
1.3 ADVANCED ENGINEERING FUNDAMENTAL KNOWLEDGE, METHODS AND TOOLS

2 PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES

2.1 ANALYTICAL REASONING AND PROBLEM SOLVING
- 2.1.1 Problem Identification and Formulation
- 2.1.2 Modeling
- 2.1.3 Estimation and Qualitative Analysis
- 2.1.4 Analysis With Uncertainty
- 2.1.5 Solution and Recommendation

2.2 EXPERIMENTATION, INVESTIGATION AND KNOWLEDGE DISCOVERY
- 2.2.1 Hypothesis Formulation
- 2.2.2 Survey of Print and Electronic Literature
- 2.2.3 Experimental Inquiry
- 2.2.4 Hypothesis Test and Defense

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 Resolution

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
- 2.4.3 Creative Thinking
- 2.4.4 Critical Thinking
- 2.4.5 Self-awareness, Metacognition and Knowledge Integration
- 2.4.6 Lifelong Learning and Educating
- 2.4.7 Time and Resource Management

2.5 ETHICS, EQUITY AND OTHER RESPONSIBILITIES
- 2.5.1 Ethics, Integrity and Social Responsibility
- 2.5.2 Professional Behavior
- 2.5.3 Proactive Vision and Intention in Life
- 2.5.4 Staying Current on the World of Engineering
- 2.5.5 Equity and Diversity
- 2.5.6 Trust and Loyalty

3 INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION

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

3.3 COMMUNICATIONS IN FOREIGN LANGUAGES
- 3.3.1 Communications in English
- 3.3.2 Communications in Languages of Regional Nations
- 3.3.3 Communications in Other Languages

4 CONCEIVING, DESIGNING, IMPLEMENTING, AND OPERATING SYSTEMS IN THE ENTERPRISE, SOCIETAL AND ENVIRONMENTAL CONTEXT – THE INNOVATION PROCESS

4.1 EXTERNAL, SOCIETAL, AND ENVIRONMENTAL CONTEXT
- 4.1.1 Roles and Responsibility of Engineers
- 4.1.2 The Impact of Engineering on Society and the Environment

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
4.1.7 Sustainability and the Need for Sustainable Development

4.2 ENTERPRISE AND BUSINESS CONTEXT
4.2.1 Appreciating Different Enterprise Cultures
4.2.2 Enterprise Stakeholders, Strategy and Goals
4.2.3 Technical Entrepreneurship
4.2.4 Working in Organizations
4.2.5 Working in International Organizations
4.2.6 New Technology Development and Assessment
4.2.7 Engineering Project Finance and Economics

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
4.3.4 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 a Sustainable Implementation Process
4.5.2 Hardware Manufacturing Process
4.5.3 Software Implementing Process
4.5.4 Hardware Software Integration
4.5.5 Test, Verification, Validation, and Certification
4.5.6 Implementation Management

4.6 OPERATING
4.6.1 Designing and Optimizing Sustainable and Safe Operations
4.6.2 Training and Operations
4.6.3 Supporting the System Life Cycle
4.6.4 System Improvement and Evolution
4.6.5 Disposal and Life-End Issues
4.6.6 Operations Management

CONDENSED EXTENDED CDIO SYLLABUS: LEADERSHIP AND ENTREPRENEURSHIP

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
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

4.8 ENTREPRENEURSHIP
4.8.1 Company Founding, Formulation, Leadership and Organization
4.8.2 Business Plan Development
4.8.3 Company Capitalization and Finances
4.8.4 Innovative Product Marketing
4.8.5 Conceiving Products and Services around New Technologies
4.8.6 The Innovation System, Networks, Infrastructure and Services
4.8.7 Building the Team and Initiating Engineering Processes
4.8.8 Managing Intellectual Property

APPENDIX B

The CDIO Syllabus v2.0
June 2011

1 DISCIPLINARY KNOWLEDGE AND REASONING (UNESCO: LEARNING TO KNOW)

1.1 KNOWLEDGE OF UNDERLYING MATHEMATICS AND SCIENCES [3a]

1.1.1 Mathematics (including statistics)
1.1.2 Physics
1.1.3 Chemistry
1.1.4 Biology

1.2 CORE ENGINEERING FUNDAMENTAL KNOWLEDGE [3a]

1.3 ADVANCED ENGINEERING FUNDAMENTAL KNOWLEDGE, METHODS AND TOOLS [3k]

2 PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES (UNESCO: LEARNING TO BE)

2.1 ANALYTIC REASONING AND PROBLEM SOLVING [3e]

2.1.1 Problem Identification and Formulation
Data and symptoms
Assumptions and sources of bias
Issue prioritization in context of overall goals
A plan of attack (incorporating model, analytical and numerical solutions, qualitative analysis, experimentation and consideration of uncertainty)

2.1.2 Modeling
Assumptions to simplify complex systems and environment
Conceptual and qualitative models
Quantitative models and simulations

2.1.3 Estimation and Qualitative Analysis
Orders of magnitude, bounds and trends
Tests for consistency and errors (limits, units, etc.)
The generalization of analytical solutions

2.1.4 Analysis with Uncertainty
Incomplete and ambiguous information
Probabilistic and statistical models of events and sequences
Engineering cost-benefit and risk analysis
Decision analysis
Margins and reserves

2.1.5 Solution and Recommendation
Problem solutions
Essential results of solutions and test data
Discrepancies in results
Summary recommendations
Possible improvements in the problem solving process

2.2 EXPERIMENTATION, INVESTIGATION AND KNOWLEDGE DISCOVERY [3b]

2.2.1 Hypothesis Formulation
Critical questions to be examined
Hypotheses to be tested
Controls and control groups

2.2.2 Survey of Print and Electronic Literature
The literature and media research strategy

See UNESCO, Four Pillars of Learning.
See ABET EC 2010, Criteria 3a – 3 k.

Information search and identification using library, on-line and database tools
Sorting and classifying the primary information
The quality and reliability of information
The essentials and innovations contained in the information
Research questions that are unanswered
Citations to references

2.2.3 Experimental Inquiry

The experimental concept and strategy
The precautions when humans are used in experiments
Investigations based on social science methods
Experiment construction
Test protocols and experimental procedures
Experimental measurements
Experimental data
Experimental data vs. available models

2.2.4 Hypothesis Test and Defense

The statistical validity of data
The limitations of data employed
Conclusions, supported by data, needs and values
Possible improvements in knowledge discovery process

2.3 SYSTEM THINKING

2.3.1 Thinking Holistically

A system, its function and behavior, and its elements
Transdisciplinary approaches that ensure the system is understood from all relevant perspectives
The societal, enterprise and technical context of the system
The interactions external to the system, and the behavioral impact of the system

2.3.2 Emergence and Interactions in Systems

The abstractions necessary to define and model the entities or elements of the system
The important relationships, interactions and interfaces among elements
The functional and behavioral properties (intended and unintended) that emerge from the system
Evolutionary adaptation over time

2.3.3 Prioritization and Focus

All factors relevant to the system in the whole
The driving factors from among the whole
Energy and resource allocations to resolve the driving issues

2.3.4 Trade-offs, Judgment and Balance in Resolution

Tensions and factors to resolve through trade-offs
Solutions that balance various factors, resolve tensions and optimize the system as a whole
Flexible vs. optimal solutions over the system lifetime
Possible improvements in the system thinking used

2.4 ATTITUDES, THOUGHT AND LEARNING

2.4.1 Initiative and Willingness to Make Decisions in the Face of Uncertainty

The needs and opportunities for initiative
Leadership in new endeavors, with a bias for appropriate action
Decisions, based on the information at hand
Development of a course of action
The potential benefits and risks of an action or decision

2.4.2 Perseverance, Urgency and Will to Deliver, Resourcefulness and Flexibility

Sense of responsibility for outcomes
Self-confidence, courage and enthusiasm
Determination to accomplish objectives

See UNESCO, Four Pillars of Learning.
See ABET EC 2010, Criteria 3a – 3 k.

The importance of hard work, intensity and attention to detail
Definitive action, delivery of results and reporting on actions
Adaptation to change
Making ingenious use of the resources of the situation or group
A readiness, willingness and ability to work independently
A willingness to work with others, and to consider and embrace various viewpoints
An acceptance of feedback, criticism and willingness to reflect and respond
The balance between personal and professional life

2.4.3 *Creative Thinking*
Conceptualization and abstraction
Synthesis and generalization
The process of invention
The role of creativity in art, science, the humanities and technology

2.4.4 *Critical Thinking*
Purpose and statement of the problem or issue
Assumptions
Logical arguments (and fallacies) and solutions
Supporting evidence, facts and information
Points of view and theories
Conclusions and implications
Reflection on the quality of the thinking

2.4.5 *Self-Awareness, Metacognition and Knowledge Integration*
One's skills, interests, strengths and weaknesses
The extent of one's abilities, and one's responsibility for self-improvement to overcome important weaknesses
The importance of both depth and breadth of knowledge
Identification of how effectively and in what way one is thinking
Linking knowledge together and identifying the structure of knowledge

2.4.6 *Lifelong Learning and Educating* **[3i]**
The motivation for continued self-education
The skills of self-education
One's own learning styles
Relationships with mentors
Enabling learning in others

2.4.7 *Time and Resource Management*
Task prioritization
The importance and/or urgency of tasks
Efficient execution of tasks

2.5 ETHICS, EQUITY AND OTHER RESPONSIBILITIES [3f]

2.5.1 *Ethics, Integrity and Social Responsibility*
One's ethical standards and principles
The moral courage to act on principle despite adversity
The possibility of conflict between professionally ethical imperatives
A commitment to service
Truthfulness
A commitment to help others and society more broadly

2.5.2 *Professional Behavior*
A professional bearing
Professional courtesy
International customs and norms of interpersonal contact

2.5.3 *Proactive Vision and Intention in Life*
A personal vision for one's future
Aspiration to exercise his/her potentials as a leader
One's portfolio of professional skills

See UNESCO, Four Pillars of Learning.
See ABET EC 2010, Criteria 3a – 3 k.

Considering one's contributions to society
Inspiring others

2.5.4 Staying Current on the World of Engineering
The potential impact of new scientific discoveries
The social and technical impact of new technologies and innovations
A familiarity with current practices/technology in engineering
The links between engineering theory and practice

2.5.5 Equity and Diversity
A commitment to treat others with equity
Embracing diversity in groups and workforce
Accommodating diverse backgrounds

2.5.6 Trust and Loyalty
Loyalty to one's colleagues and team
Recognizing and emphasizing the contributions of others
Working to make others successful

3 INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION (UNESCO: LEARNING TO LIVE TOGETHER)

3.1 TEAMWORK [3d]

3.1.1 Forming Effective Teams
The stages of team formation and life cycle
Task and team processes
Team roles and responsibilities
The goals, needs and characteristics (works styles, cultural differences) of individual team members
The strengths and weaknesses of the team and its members
Ground rules on norms of team confidentiality, accountability and initiative

3.1.2 Team Operation
Goals and agenda
The planning and facilitation of effective meetings
Team ground rules
Effective communication (active listening, collaboration, providing and obtaining information)
Positive and effective feedback
The planning, scheduling and execution of a project
Solutions to problems (team creativity and decision making)
Conflict mediation, negotiation and resolution
Empowering those on the team

3.1.3 Team Growth and Evolution
Strategies for reflection, assessment and self-assessment
Skills for team maintenance and growth
Skills for individual growth within the team
Strategies for team communication and reporting

3.1.4 Team Leadership
Team goals and objectives
Team process management
Leadership and facilitation styles (directing, coaching, supporting, delegating)
Approaches to motivation (incentives, example, recognition, etc.)
Representing the team to others
Mentoring and counseling

3.1.5 Technical and Multidisciplinary Teaming
Working in different types of teams:
Cross-disciplinary teams (including non-engineer)

See UNESCO, Four Pillars of Learning.
See ABET EC 2010, Criteria 3a – 3 k.

Small team vs. large team
Distance, distributed and electronic environments
Technical collaboration with team members
Working with non-technical members and teams

3.2 COMMUNICATIONS [3g]

3.2.1 Communications Strategy
The communication situation
Communications objectives
The needs and character of the audience
The communication context
A communications strategy
The appropriate combination of media
A communication style (proposing, reviewing, collaborating, documenting, teaching)
The content and organization

3.2.2 Communications Structure
Logical, persuasive arguments
The appropriate structure and relationship amongst ideas
Relevant, credible, accurate supporting evidence
Conciseness, crispness, precision and clarity of language
Rhetorical factors (e.g. audience bias)
Cross-disciplinary cross-cultural communications

3.2.3 Written Communication
Writing with coherence and flow
Writing with correct spelling, punctuation and grammar
Formatting the document
Technical writing
Various written styles (informal, formal memos, reports, resume, etc.)

3.2.4 Electronic/Multimedia Communication
Preparing electronic presentations
The norms associated with the use of e-mail, voice mail, and videoconferencing
Various electronic styles (charts, web, etc)

3.2.5 Graphical Communications
Sketching and drawing
Construction of tables, graphs and charts
Formal technical drawings and renderings
Use of graphical tools

3.2.6 Oral Presentation
Preparing presentations and supporting media with appropriate language, style, timing and flow
Appropriate nonverbal communications (gestures, eye contact, poise)
Answering questions effectively

3.2.7 Inquiry, Listening and Dialog
Listening carefully to others, with the intention to understand
Asking thoughtful questions of others
Processing diverse points of view
Constructive dialog
Recognizing ideas that may be better than your own

3.2.8 Negotiation, Compromise and Conflict Resolution
Identifying potential disagreements, tensions or conflicts
Negotiation to find acceptable solutions
Reaching agreement without compromising fundamental principles
Diffusing conflicts

3.2.9 Advocacy
Clearly explaining one's point of view

See UNESCO, Four Pillars of Learning.
See ABET EC 2010, Criteria 3a – 3 k.

Explaining how one reached an interpretation or conclusion
Assessing how well you are understood
Adjusting approach to advocacy on audience characteristics

3.2.10 Establishing Diverse Connections and Networking

Appreciating those with different skills, cultures or experiences
Engaging and connecting with diverse individuals
Building extended social networks
Activating and using networks to achieve goals

3.3 COMMUNICATIONS IN FOREIGN LANGUAGES

3.3.1 Communications in English

3.3.2 Communications in Languages of Regional Commerce and Industry

3.3.3 Communications in Other Languages

4 CONCEIVING, DESIGNING, IMPLEMENTING AND OPERATING SYSTEMS IN THE ENTERPRISE, SOCIETAL AND ENVIRONMENTAL CONTEXT – THE INNOVATION PROCESS (UNESCO: LEARNING TO DO)

4.1 EXTERNAL, SOCIETAL AND ENVIRONMENTAL CONTEXT [3h]

4.1.1 Roles and Responsibility of Engineers

The goals and roles of the engineering profession
The responsibilities of engineers to society and a sustainable future

4.1.2 The Impact of Engineering on Society and the Environment

The impact of engineering on the environmental, social, knowledge and economic systems in modern culture

4.1.3 Society's Regulation of Engineering

The role of society and its agents to regulate engineering
The way in which legal and political systems regulate and influence engineering
How professional societies license and set standards
How intellectual property is created, utilized and defended

4.1.4 The Historical and Cultural Context

The diverse nature and history of human societies as well as their literary, philosophical and artistic traditions
The discourse and analysis appropriate to the discussion of language, thought and values

4.1.5 Contemporary Issues and Values **[3j]**

The important contemporary political, social, legal and environmental issues and values
The processes by which contemporary values are set, and one's role in these processes
The mechanisms for expansion and diffusion of knowledge

4.1.6 Developing a Global Perspective

The internationalization of human activity
The similarities and differences in the political, social, economic, business and technical norms of various cultures
International and intergovernmental agreements and alliances

4.1.7 Sustainability and the Need for Sustainable Development

Definition of sustainability
Goals and importance of sustainability
Principles of sustainability
Need to apply sustainability principles in engineering endeavors

4.2 ENTERPRISE AND BUSINESS CONTEXT

4.2.1 Appreciating Different Enterprise Cultures

The differences in process, culture, and metrics of success in various enterprise cultures: Corporate vs. academic vs. governmental vs. non-profit/NGO

See UNESCO, Four Pillars of Learning.
See ABET EC 2010, Criteria 3a – 3 k.

Market vs. policy driven
Large vs. small
Centralized vs. distributed
Research and development vs. operations
Mature vs. growth phase vs. entrepreneurial
Longer vs. faster development cycles
With vs. without the participation of organized labor

4.2.2 Enterprise Stakeholders, Strategy and Goals
The stakeholders and beneficiaries of an enterprise (owners, employees, customers, etc.)
Obligations to stakeholders
The mission, scope and goals of the enterprise
Enterprise strategy and resource allocation
An enterprise's core competence and markets
Key alliances and supplier relations

4.2.3 Technical Entrepreneurship
Entrepreneurial opportunities that can be addressed by technology
Technologies that can create new products and systems
Entrepreneurial finance and organization

4.2.4 Working in Organizations
The function of management
Various roles and responsibilities in an organization
The roles of functional and program organizations
Working effectively within hierarchy and organizations
Change, dynamics and evolution in organizations

4.2.5 Working in International Organizations
Culture and tradition of enterprise as a reflection of national culture
Equivalence of qualifications and degrees
Governmental regulation of international work

4.2.6 New Technology Development and Assessment
The research and technology development process
Identifying and assessing technologies
Technology development roadmaps
Intellectual property regimes and patents

4.2.7 Engineering Project Finance and Economics
Financial and managerial goals and metrics
Project finance – investments, return, timing
Financial planning and control
Impact of projects on enterprise finance, income and cash

4.3 CONCEIVING, SYSTEM ENGINEERING AND MANAGEMENT [3c]

4.3.1 Understanding Needs and Setting Goals
Needs and opportunities
Customer needs, and those of the market
Opportunities that derive from new technology or latent needs
Environmental needs
Factors that set the context of the system goals
Enterprise goals, strategies, capabilities and alliances
Competitors and benchmarking information
Ethical, social, environmental, legal and regulatory influences
The probability of change in the factors that influence the system, its goals and resources available
System goals and requirements
The language/format of goals and requirements
Initial target goals (based on needs, opportunities and other influences)
System performance metrics

See UNESCO, Four Pillars of Learning.
See ABET EC 2010, Criteria 3a – 3 k.

Requirement completeness and consistency

4.3.2 Defining Function, Concept and Architecture

Necessary system functions (and behavioral specifications)
System concepts
Incorporation of the appropriate level of technology
Trade-offs among and recombination of concepts
High-level architectural form and structure
The decomposition of form into elements, assignment of function to elements, and definition of interfaces

4.3.3 System Engineering, Modeling and Interfaces

Appropriate models of technical performance and other attributes
Consideration of implementation and operations
Life cycle value and costs (design, implementation, operations, opportunity, etc.)
Trade-offs among various goals, function, concept and structure and iteration until convergence
Plans for interface management

4.3.4 Development Project Management

Project control for cost, performance and schedule
  Appropriate transition points and reviews
  Configuration management and documentation
  Performance compared to baseline
Earned value recognition
The estimation and allocation of resources
Risks and alternatives
Possible development process improvements

4.4 DESIGNING [3c]

4.4.1 The Design Process

Requirements for each element or component derived from system level goals and requirements
Alternatives in design
The initial design
Life cycle consideration in design
Experimental prototypes and test articles in design development
Appropriate optimization in the presence of constraints
Iteration until convergence
The final design
Accommodation of changing requirements

4.4.2 The Design Process Phasing and Approaches

The activities in the phases of system design (e.g. conceptual, preliminary and detailed design)
Process models appropriate for particular development projects (waterfall, spiral, concurrent, etc.)
The process for single, platform and derivative products

4.4.3 Utilization of Knowledge in Design

Technical and scientific knowledge
Modes of thought (problem solving, inquiry, system thinking, creative and critical thinking)
Prior work in the field, standardization and reuse of designs (including reverse engineering and refactoring, redesign)
Design knowledge capture

4.4.4 Disciplinary Design

Appropriate techniques, tools and processes
Design tool calibration and validation
Quantitative analysis of alternatives

See UNESCO, Four Pillars of Learning.
See ABET EC 2010, Criteria 3a – 3 k.

Modeling, simulation and test
Analytical refinement of the design

4.4.5 Multidisciplinary Design

Interactions between disciplines
Dissimilar conventions and assumptions
Differences in the maturity of disciplinary models
Multidisciplinary design environments
Multidisciplinary design

4.4.6 Design for Sustainability, Safety, Aesthetics, Operability and Other Objectives

Design for:
- Performance, quality, robustness, life cycle cost and value
- Sustainability
- Safety and security
- Aesthetics
- Human factors, interaction and supervision
- Implementation, verification, test and environmental sustainability
- Operations
- Maintainability, dependability and reliability
- Evolution, product improvement
- Retirement, reusability and recycling

4.5 IMPLEMENTING [3c]

4.5.1 Designing a Sustainable Implementation Process

The goals and metrics for implementation performance, cost and quality
The implementation system design:
- Task allocation and cell/unit layout
- Work flow
- Considerations for human user/operators

Consideration of sustainability

4.5.2 Hardware Manufacturing Process

The manufacturing of parts
The assembly of parts into larger constructs
Tolerances, variability, key characteristics and statistical process control

4.5.3 Software Implementing Process

The break down of high-level components into module designs (including algorithms and data structures)
Algorithms (data structures, control flow, data flow)
The programming language and paradigms
The low-level design (coding)
The system build

4.5.4 Hardware Software Integration

The integration of software in electronic hardware (size of processor, communications, etc.)
The integration of software with sensor, actuators and mechanical hardware
Hardware/software function and safety

4.5.5 Test, Verification, Validation and Certification

Test and analysis procedures (hardware vs. software, acceptance vs. qualification)
The verification of performance to system requirements
The validation of performance to customer needs
The certification to standards

4.5.6 Implementation Management

The organization and structure for implementation
Sourcing and partnering
Supply chains and logistics
Control of implementation cost, performance and schedule

See UNESCO, Four Pillars of Learning.
See ABET EC 2010, Criteria 3a – 3 k.

Quality assurance
Human health and safety
Environmental security
Possible implementation process improvements

4.6 OPERATING [3c]

4.6.1 Designing and Optimizing Sustainable and Safe Operations

The goals and metrics for operational performance, cost and value
Sustainable operations
Safe and secure operations
Operations process architecture and development
Operations (and mission) analysis and modeling

4.6.2 Training and Operations

Training for professional operations:
- Simulation
- Instruction and programs
- Procedures

Education for consumer operation
Operations processes
Operations process interactions

4.6.3 Supporting the System Life Cycle

Maintenance and logistics
Life cycle performance and reliability
Life cycle value and costs
Feedback to facilitate system improvement

4.6.4 System Improvement and Evolution

Pre-planned product improvement
Improvements based on needs observed in operation
Evolutionary system upgrades
Contingency improvements/solutions resulting from operational necessity

4.6.5 Disposal and Life-End Issues

The end of useful life
Disposal options
Residual value at life-end
Environmental considerations for disposal

4.6.6 Operations Management

The organization and structure for operations
Partnerships and alliances
Control of operations cost, performance and scheduling
Quality and safety assurance
Possible operations process improvements
Life cycle management
Human health and safety
Environmental security

The Extended CDIO Syllabus: Leadership and Entrepreneurship

This extension to the CDIO Syllabus is provided as a resource for programs that seek to respond to stakeholder expressed needs in the areas of Engineering Leadership and Entrepreneurship

4.7 LEADING ENGINEERING ENDEAVORS

Engineering Leadership builds on factors already included above, including:

- **Attitudes of Leadership – Core Personal Values and Character,** including topics in Attitudes, Thought and Learning (2.4), and in Ethics, Equity and Other Responsibilities (2.5)

See UNESCO, Four Pillars of Learning.
See ABET EC 2010, Criteria 3a – 3 k.

- **Relating to Others**, including topics in Teamwork (3.1), Communications (3.2) and potentially Communications in Foreign Languages (3.3)
- **Making Sense of Context**, including topics in External, Societal and Environmental Context (4.1), Enterprise and Business Context (4.2) Conceiving, Systems Engineering and Management (4.3) and System Thinking (2.3)

In addition there are several topics that constitute creating a **Purposeful Vision**:

4.7.1 Identifying the Issue, Problem or Paradox (which builds on Understanding Needs and Setting Goals 4.3.1)

Synthesizing the understanding of needs or opportunities (that technical systems can address)
Clarifying the central issues
Framing the problem to be solved
Identifying the underlying paradox to be examined

4.7.2 Thinking Creatively and Communicating Possibilities (which builds on and expands Creative Thinking 2.4.3)

How to create new ideas and approaches
New visions of technical systems that meet the needs of customers and society
Communicating visions for products and enterprises
Compelling visions for the future

4.7.3 Defining the Solution (which builds on and expands Understanding Needs and Setting Goals 4.3.1)

The vision for the engineering solution
Achievable goals for quality performance, budget and schedule
Consideration of customer and beneficiary
Consideration of technology options
Consideration of regulatory, political and competitive forces

4.7.4 Creating New Solution Concepts (which builds on and expands 4.3.2 and 4.3.3)

Setting requirements and specifications
The high-level concept for the solution
Architecture and interfaces
Alignment with other projects of the enterprise
Alignment with enterprise strategy, resources and infrastructure

And several topics that lead to **Delivering on the Vision:**

4.7.5 Building and Leading an Organization and Extended Organization (which builds on 4.2.4 and 4.2.5)

Recruiting key team members with complementary skills
Start-up of team processes, and technical interchange
Defining roles, responsibilities and incentives
Leading group decision-making
Assessing group progress and performance
Building the competence of others and succession
Partnering with external competence

4.7.6 Planning and Managing a Project to Completion (which builds on 4.3.4)

Plans of action and alternatives to deliver completed projects on time
Deviation from plan, and re-planning
Managing human, time, financial and technical resources to meet plan
Program risk, configuration and documentation
Program economics and the impact of decisions on them

4.7.7 Exercising Project/Solution Judgment and Critical Reasoning (which builds on 2.3.4 and 2.4.4)

Making complex technical decisions with uncertain and incomplete information
Questioning and critically evaluating the decisions of others
Corroborating inputs from several sources

See UNESCO, Four Pillars of Learning.
See ABET EC 2010, Criteria 3a – 3 k.

Evaluating evidence and identifying the validity of key assumptions
Understanding alternatives that are proposed by others
Judging the expected evolution of all solutions in the future

4.7.8 Innovation – the Conception, Design and Introduction of New Goods and Services (which is the leadership of 4.3 and 4.4)
Designing and introducing new goods and services to the marketplace
Designing solutions to meet customer and societal needs
Designing solutions with the appropriate balance of new and existing technology
Robust, flexible and adaptable products
Consideration of current and future competition
Validating the effectiveness of the solution

4.7.9 Invention – the Development of New Devices, Materials or Processes that Enable New Goods and Services (which builds on 4.2.6)
Science and technology basis and options
Imagining possibilities
Inventing a practical device or process that enables a new product or solution
Adherence to intellectual property regimes

4.7.10 Implementation and Operation – the Creation and Operation of the Goods and Services that will Deliver Value (which are the leadership of 4.5 and 4.6)
Leading implementing and operating
Importance of quality
Safe operations
Operations to deliver value to the customer and society

These last three items are in fact the leadership of the core processes of engineering: conceiving, designing, implementing and operating

4.8 ENGINEERING ENTREPRENEURSHIP

Engineering Entrepreneurship includes by reference all of the aspects of Societal and Enterprise Context (4.1 and 4.2), all of the skills of Conceiving, Designing, Implementing and Operating (4.3 – 4.6) and all of the elements of Engineering Leadership (4.7).

In addition, there are the entrepreneurship specific skills:

4.8.1 Company Founding, Formulation, Leadership and Organization
Creating the corporate entity and financial infrastructure
Team of supporting partners (bank, lawyer, accounting, etc.)
Consideration of local labor law and practices
The founding leadership team
The initial organization
The board of the company
Advisors to the company

4.8.2 Business Plan Development
A need in the world that you will fill
A technology that can become a product
A team that can develop the product
Plan for development
Uses of capital
Liquidity strategy

4.8.3 Company Capitalization and Finances
Capital needed, and timing of need (to reach next major milestone)
Investors as sources of capital
Alternative sources of capital (government, etc.)
Structure of investment (terms, price, etc.)
Financial analysis for investors
Management of finances
Expenditures against intermediate milestones of progress

See UNESCO, Four Pillars of Learning.
See ABET EC 2010, Criteria 3a – 3 k.

4.8.4 Innovative Product Marketing

Size of potential market
Competitive analyses
Penetration of market
Product positioning
Relationships with customers
Product pricing
Sales initiation
Distribution to customers

4.8.5 Conceiving Products and Services around New Technologies

New technologies available
Assessing the readiness of technology
Assessing the ability of your enterprise to innovate based on the technology
Assessing the product impact of the technology
Accessing the technologies though partnerships, licenses, etc.
A team to productize the technology

4.8.6 The Innovation System, Networks, Infrastructure and Services

Relationships for enterprise success
Mentoring of the enterprise leadership
Supporting financial services
Investor networks
Suppliers

4.8.7 Building the Team and Initiating Engineering Processes (conceiving, designing, implementing and operating)

Hiring the right skill mix
Technical process startup
Building an engineering culture
Establishing enterprise processes

4.8.8 Managing Intellectual Property

IP landscape for your product or technology
IP strategy – offensive and defensive
Filing patents and provisional patents
IP legal support
Entrepreneurial opportunities that can be addressed by technology
Technologies that can create new products and systems
Entrepreneurial finance and organization

See UNESCO, Four Pillars of Learning.
See ABET EC 2010, Criteria 3a – 3 k.