The CDIO Syllabus
A comparative study of expected student proficiency

Johan Bankel
Chalmers University of Technology, Göteborg, Sweden
+46 31 772 1174, 1174
joba@kanslim.chalmers.se

Karl-Fredrik Berggren
Linköping University, Linköping, Sweden
+46 13 281 203
kfb@ifm.liu.se

Karin Blom
Royal Institute of Technology (KTH), Stockholm, Sweden
+46 87 907 528
karblo@kth.se

Edward F. Crawley
Massachusetts Institute of Technology, Cambridge, Massachusetts, USA.
+1 617 253 7510
crawley@mit.du

Ingela Wiklund
Linköping University, Linköping, Sweden
+46 13 281 098
ingwi@tfk.liu.se

Sören Östlund
Royal Institute of Technology (KTH), Stockholm, Sweden
+46 8 790 7542
soren@hallf.kth.se

November 2002

Authors

Johan Bankel, is a coordinator for the Mechanical Engineering programme at Chalmers University of Technology in Göteborg, Sweden. He has a M.Sc. in Naval Architecture, a Lic. Tech. in fluid dynamics and a teacher certificate in natural science.

Karl-Fredrik Berggren is a professor of theoretical physics in the Department of Physics and Measurement Technology at Linköping University, in Sweden. He has a Ph.D. in Quantum Chemistry.

Karin Blom is a programme coordinator in the Office of the School of Mechanical and Materials Engineering at the Royal Institute of Technology in Stockholm. She has a Bachelor of Social Science degree.

Edward F. Crawley is a professor and head of the Massachusetts Institute of Technology Department of Aeronautics and Astronautics in the USA. He has S.B. and S.M. degrees in aeronautics and astronautics, and an Sc.D. in structural dynamics. He is the program director for the CDIO Initiative at MIT.

Sören Östlund is professor of packaging technology and chairman of the Vehicle Engineering Program at the Royal Institute of Technology (KTH) in Stockholm. He has an M.Sc. in aeronautical engineering and a Ph.D. in solid mechanics. He is the program director for the CDIO Initiative at KTH.

Ingela Wiklund is director of studies for the M.Sc. program in Applied Physics and Electrical Engineering at Linköping University, in Sweden. She has an M.Sc. degree in Applied Physics and Electrical Engineering, branch Biomedical Engineering.

Abstract

Engineering students must graduate with command of a vast body of technical knowledge. They must possess personal, interpersonal and system building skills to function in teams, and be prepared to produce products and systems. Their education must have been structured under a curriculum blending ability to combine technical expertise with ethical, innovative, philosophical and humanistic acumen.

This paper describes a unique international collaboration among four universities to reform engineering education. The collaborators agreed to a statement of goals, which includes descriptions of knowledge, skills and attitudes vital to an effective education, and codifies proficiency levels expected of graduates. We developed and utilized unique stakeholder surveys to both validate our prototype and determine desired proficiency levels. This collaboration resulted in *The CDIO Syllabus, A Statement of Goals for Undergraduate Engineering Education*.

The Syllabus is both a template and a process that can be used to customize the syllabus to others' programs. It can define new educational initiatives, and be employed as the basis for rigorous assessment.

This paper details how, with the input of industry, academia and others, we employed an engineering problem solving paradigm to effect our redesign. It outlines the Syllabus and the unique process employed to create it.

Introduction

In both Europe and the USA, we are entering an era of intense re-evaluation of engineering education. In the EU, this is, in part, precipitated by the Bologna Declaration[1], while in the USA it is encouraged by the transition to the Accreditation Board for Engineering and Technology (ABET)[2] EC2000 accreditation criteria. As we enter this era of re-evaluation, it is important to understand the goals of engineering education. Ideally, we would agree to a statement of goals that would contain not only a description of the knowledge, skills and attitudes appropriate to university education, but also an indication of the level of proficiency expected of graduating students. Such a document would provide the basis for rational curricular and pedagogic improvement, and for outcome-based assessment.

This paper describes an international effort to create such a statement of goals. The result, after three years of research, is *The CDIO Syllabus, A Statement of Goals for Undergraduate Engineering Education*. The effort was a collaboration of Chalmers University of Technology, Royal Institute of Technology (KTH) and Linköping University (LiU) in Sweden; and the Massachusetts Institute of Technology (MIT) in the USA[3]. The CDIO Syllabus was derived as part of a larger educational research programme in engineering education --- the CDIO Initiative.

The CDIO Initiative's educational objective is to address one of the central issues of contemporary engineering education — how does a university continue to provide a quality education in the technical fundamentals, while simultaneously imparting a sense of engineering professionalism. The latter refers to that broad set of skills necessary to work effectively to build systems and products --- the real job of engineers.

The starting point of our initiative was a restatement of the underlying *need* for engineering education. We believe that every graduating engineer should be able to:

__C__onceive-__D__esign-__I__mplement-__O__perate
complex value-added engineering systems
in a modern team-based environment

The emphasis on the product/system lifecycle (Conceive-Design-Implement-Operate) gives the initiative and the Syllabus its name. 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.

In our partnership, we are using an *engineering problem solving paradigm* to approach the redesign of the education. This calls for a translation of the underlying need stated above into a formal set of *goals*, against which we can then design. This is the role of the CDIO Syllabus, as will be discussed below.

The CDIO Initiative's *concept* is to provide students with an education stressing the technical fundamentals, and prepares students to be successful in the role of developing systems and products. The approach has four constituent parts: curricular redesign, pedagogical improvement, learning-space creation and continuous assessment. The curriculum of this new educational model is integrated, with interwoven and mutually supporting disciplines[4]. Pedagogically, students learn experientially through increasingly active experiences that make dual use of time, allowing learning of fundamentals and professional skills[5, 6]. The education makes extensive use of team-based design-build-operate projects, in both modern classrooms and workshop laboratories[7]. By developing a set of authentic personal technical experiences, students learn about system building *and* they better master the deep working knowledge of the fundamentals. Wrapped around the education is a comprehensive assessment process for continuous improvement[8, 9].

The objective of this paper is to outline the CDIO Syllabus in terms of its content, the process used to derive it and the expected levels of proficiency. The Syllabus is a list of topics, determined through a consensus process to be the appropriate list of knowledge, skills and attitudes possessed by graduating engineers. However, to translate this list of skills into a statement of goals, a further process is required to establish an expected level of proficiency in each of the skills by the time of graduation. Our partnership developed a survey-based process for determining these levels of proficiency. The surveys were conducted at our four universities, yielding unique data on comparative expectations among various stakeholders, in various technical disciplines, and in the USA and Sweden. In this paper we summarize these levels of expected results, leading to some important and generalizable conclusions.

The CDIO Syllabus

The first tangible outcome of the CDIO Initiative is the CDIO Syllabus, a codification of contemporary engineering knowledge, skills and attitudes. The

Syllabus essentially constitutes a *requirements document* for undergraduate engineering education. It is both a template and an associated process. The process can be used to capture the opinions of industry, alumni and faculty, and customize the CDIO Syllabus to a set of learning objectives appropriate for any specific undergraduate engineering programme.

In assembling and organizing the Syllabus content our goal was threefold:

- to create a structure whose rationale is apparent
- to derive a comprehensive high-level set of goals correlated with other sources
- to develop a clear, complete, and consistent set of detailed topics that facilitate implementation and assessment.

The outcome of this activity is the CDIO Syllabus, shown in condensed form in Figure 1. Note that the letters in brackets correspond to specific ABET EC2000[2] Criteria 3a through 3k. (See Table 1)

1 TECHNICAL KNOWLEDGE AND REASONING
1.1 KNOWLEDGE OF UNDERLYING SCIENCE [a]
1.2 CORE ENGINEERING FUNDAMENTAL KNOWLEDGE [a]
1.3 ADVANCED ENGINEERING FUNDAMENTAL KNOWLEDGE [k]

2 PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES
2.1 ENGINEERING REASONING AND PROBLEM SOLVING [e]
2.1.1 Problem Identification and Framing
2.1.2 Modelling
2.1.3 Estimation and Qualitative Analysis
2.1.4 Analysis With Uncertainty
2.1.5 Closing the Problem

2.2 EXPERIMENTATION AND KNOWLEDGE DISCOVERY [b]
2.2.1 Principles of Research and Inquiry
2.2.2 Experimental Inquiry
2.2.3 Survey of Print and Electronic Literature
2.2.4 Hypothesis Test, and Defence

2.3 SYSTEM THINKING
2.3.1 Thinking Holistically
2.3.2 Emergence and Interactions in Systems
2.3.3 Prioritisation and Focus
2.3.4 Trade-offs and Balance

2.4 PERSONAL SKILLS AND ATTITUDES
2.4.1 Initiative and Willingness to Take Risks
2.4.2 Perseverance, and Flexibility
2.4.3 Creative Thinking
2.4.4 Critical Thinking
2.4.5 Personal Inventory
2.4.6 Curiosity and Lifelong Learning [i]
2.4.7 Time and Resource Management

2.5 PROFESSIONAL SKILLS AND ATTITUDES
2.5.1 Professional Ethics, Integrity, Responsibility and Accountability [f]
2.5.2 Professional Behaviour
2.5.3 Proactively Planning for One's Career
2.5.4 Stay Current on World of Engineer

3 INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION
3.1 MULTI-DISCIPLINARY TEAMWORK [d]
3.1.1 Form Effective Teams
3.1.2 Team Operation
3.1.3 Team Growth and Evolution
3.1.4 Leadership
3.1.5 Technical Teaming

3.2 COMMUNICATIONS [g]
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 and Inter-Personal Communications

3.3 COMMUNICATIONS IN FOREIGN LANGUAGES
3.3.1 English
3.3.2 Languages of Regional Industrial Nations
3.3.3 Other Languages

4 CONCEIVING, DESIGNING, IMPLEMENTING, AND OPERATING SYSTEMS IN THE ENTERPRISE AND SOCIETAL CONTEXT [h]
4.1 EXTERNAL AND SOCIETAL CONTEXT
4.1.1 Roles and Responsibility of Engineers
4.1.2 Understand the Impact of Engineering
4.1.3 Understand How Engineering Is Regulated
4.1.4 Knowledge of Historical and Cultural Context
4.1.5 Knowledge of Contemporary Issues and Values [j]
4.1.6 Developing a Global Perspective

4.2 ENTERPRISE AND BUSINESS CONTEXT
4.2.1 Appreciating Different Enterprise Cultures
4.2.2 Enterprise Strategy, Goals, and Planning
4.2.3 Technical entrepreneurship
4.2.4 Working successfully in Organizations

4.3 CONCEIVING AND ENGINEERING SYSTEMS [c]
4.3.1 Setting System Goals and Requirements
4.3.2 Defining Function, Concept and Architecture
4.3.3 Modelling of System and Insuring Goals Can Be Met
4.3.4 Project Management

4.4 DESIGNING [c]
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 Multi-Objective Design (DFX)

4.5 IMPLEMENTING [c]
4.5.1 Designing and Modelling of the 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 Managing Implementation

4.6 OPERATING [c]
4.6.1 Modelling, Designing and Optimising Operations
4.6.2 Training and Operations
4.6.3 Supporting the System Lifecycle
4.6.4 System Improvement and Evolution
4.6.5 Disposal and Life-End Issues
4.6.6 Operations Management

Figure 1: Condensed CDIO Syllabus, showing first, second and third level content. Letters in brackets correspond to ABET EC2000 Criteria 3a through 3k. (See Table 1)

Content and structure

The departure point for the derivation of the CDIO Syllabus' content and its underlying rationale is the simple statement that *engineers engineer*; that is, they build systems and products for the betterment of humanity. Graduating engineers should appreciate engineering *process*, be able to contribute to the development of engineering *products*, and do so while working in engineering *organizations*. This is just another way of expressing the need statement proposed above: conceive-design-implement-operate (process) complex valued-added engineering systems (product) in a modern team-based environment (organization). Implicit is the additional expectation that engineering graduates should develop as whole, mature, thoughtful individuals.

These high–level expectations map directly to the highest levels, or what we refer to as the four "X" Parts (e.g. 1 Technical Knowledge and Reasoning, 2 Personal and Professional Skills and Attributes) in the outline-format organization of the CDIO Syllabus, (see Figure. 2). Examining the mapping of the first-level Syllabus items to these four expectations, we can see that a mature, thoughtful individual interested in technical endeavours possesses a set of *Personal and Professional Skills*, which are central to the practice. In order to develop complex value-added engineering systems, students must have mastered the fundamentals of the appropriate *Technical 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, students must understand something of *Conceiving, Designing, Implementing, and Operating Systems in the Enterprise and Societal Context*.

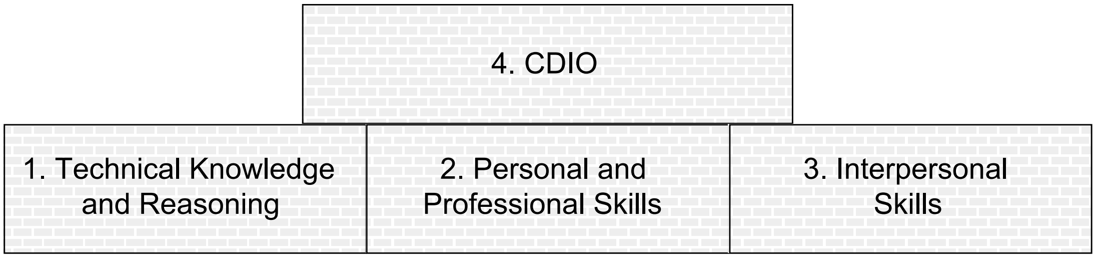


Figure 2: Building blocks of knowledge, skills, and attitudes necessary to Conceive, Design, Implement, and Operate Systems in the Enterprise and Societal Context. Compare to the Syllabus in Figure 1.

Part 1 of the Syllabus is *Technical Knowledge and Reasoning*. Modern engineering professions rely on a necessary core Knowledge of Underlying Sciences (Syllabus Level 1.1). (See Figure 1) A body of Core Engineering Fundamental Knowledge (1.2) builds on that science core, and a set of Advanced Engineering Fundamentals (1.3) moves students *towards* the skills necessary to begin a professional career. This is the curriculum that engineering school faculty usually debate and define. Therefore, the CDIO Syllabus merely leaves a placeholder here, since the Part 1 details will vary from field to field.

In the remainder of the Syllabus, we have endeavoured to include the knowledge, skills and attitudes that *all* engineering graduates might require.

Part 2 of the Syllabus is *Personal and Professional Skills and Attributes*. The three modes of thought most practiced professionally by engineers are Engineering Reasoning and Problem Solving (2.1), Experimentation and Knowledge Discovery (2.2) and System Thinking (2.3). Those personal skills and attributes, other than the three modes of thought, which are used primarily in a professional context, are called Professional Skills and Attitudes (2.5). The subset of personal skills that are not primarily used in a professional context, and are not interpersonal, are Personal Skills and Attitudes (2.4).

In Part 3, the *Interpersonal Skills* are outlined. The *Interpersonal Skills* are a distinct subset of the general class of personal skills, and divide into Teamwork (3.1), Communications (3.2) and Communications in a Foreign Language (3.3).

Part 4, *Conceiving, Designing, Implementing, and Operating Systems in the Enterprise and Societal 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. Products and systems are created and operated within an Enterprise and Business Context (4.2), and engineers' work and enterprises exist within a larger Societal and External Context (4.1).

It is important to note that the full CDIO Syllabus (as opposed to the condensed version in Figure 1) exists at up to five levels of detail. This decomposition is necessary to transition from the high-level goals (e.g. Level 3's statement that all engineers must be able to communicate) to the level of teachable and assessable skills (e.g. a topic in Level 3.2.1, "analyse the audience"). 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. However, we feel that the rationale for the document flows seamlessly from the high-level statement of needs.

Process of deriving the syllabus

The process used to arrive at the detailed content of the CDIO Syllabus was aimed at developing a comprehensive, complete and generalizable statement of goals. The process blended elements of a product development user need study with techniques from scholarly research. The Syllabus' detailed content was derived through focus group discussions, document research, surveys, workshops and peer reviews. The Syllabus was first drafted at MIT's Department of Aeronautics and Astronautics, and then reviewed and modified by the participating Swedish universities to insure trans-national and trans-disciplinary applicability[10].

The first step in gathering the detailed content of the Syllabus was interviewing focus groups, which included MIT faculty, current MIT students, industry leaders in the USA and senior academics from other USA universities. These stakeholders were highly concentrated in aerospace disciplines. To ensure applicability to all engineering fields, we included individuals with varied engineering backgrounds, generalized concepts whenever possible, and we used relatively universal terminology. The groups were presented with the question, "What, in detail, is the set of knowledge, skills and attitudes that a graduating engineer should possess?" Not surprisingly, the groups produced varied responses.

We organized results of the focus groups, plus the topics extracted from other comprehensive source documents, into a preliminary draft, which contained the first four-level organization of the content. The principal source documents used were representative of the views of USA industry, government and academia on the expectations for university graduates. They included the ABET EC2000[2] and Boeing's "Desired Attributes of a Graduating Engineer"[11].

This preliminary draft needed extensive review and validation. To obtain stakeholder feedback, a survey was conducted among four constituencies: senior USA industry leaders, MIT faculty, younger alumni and older alumni. The qualitative comments from this survey were incorporated, improving the Syllabus' organization, clarity and coverage.

Each second level, or X.X, section of the Syllabus (e.g. 1.1 Knowledge of Underlying Science) was then reviewed by several domain experts. Combining the results of the peer reviews, and a check of additional sectional references, we completed the draft topical version of the Syllabus.

The entire draft Syllabus underwent a comprehensive review by the three Swedish university teams, including translation into Swedish. The Swedish professors examined the document from two perspectives; one to determine its adaptability to other engineering fields, and one to consider the imbedded cultural issues from a national perspective. From the trans-disciplinary view, the Swedish partners, who represent programmes in vehicle engineering, mechanical engineering and applied physics/electrical engineering (see programme descriptions below), recommended minor changes and clarifications, but, in general, found Parts 2, 3 and 4 of the Syllabus to be completely adaptable to their disciplines. From a cultural perspective, the only major change that was made was the inclusion of Section 3.3, Communications in a Foreign Language. It is interesting to note that at no time in the USA deliberations did the subject of an engineer learning a foreign language arise.

To ensure comprehensiveness and to facilitate comparison, the contents of the Syllabus were explicitly correlated with the comprehensive source documents. As an example, the correlation with ABET's EC2000 is presented. EC2000 Criterion 3 states that accredited engineering programmes must assure that their graduates have developed 11 specific attributes. (See Table 1) While coverage by the CDIO Syllabus of ABET's attributes is strong, the Syllabus is more comprehensive, as indicated in Figure 1. The closest mapping of ABET EC2000 Criteria 3 items onto the CDIO Syllabus is indicated by the notations of [a] through [k]. One will observe that there are entire areas that EC2000 does not address, such as System Thinking (2.3) and Operations (4.6).

a. An ability to apply knowledge of mathematics, science, and engineering.
b. An ability to design and conduct experiments, as well as to analyse and interpret data.
c. An ability to design a system, component, or process to meet desired needs.
d. An ability to function on multi-disciplinary 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 and societal 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.

Table 1: ABET EC2000 accreditation requirements, Criterion 3 (ABET, 2000).

Programmes and universities studied

Before examining our survey process and responses, and trying to understand their similarities and differences, it is useful to present a synopsis of the four participating programmes. All are major educational programmes within leading research universities that have firm commitments to education. The programmes differ in national and disciplinary character. The USA-to-Swedish comparison rests not only on national culture, but also secondary school preparation, length of degree programme, and relationship between universities and industry. The four programmes represent a disciplinary span that includes mechanical, applied physics/electrical and aerospace engineering. The aerospace programme at MIT and the vehicle programme at KTH were chosen to be as close as possible in disciplinary nature, so as to isolate potential discipline and national influences.

Swedish University engineering programmes

Most of the Swedish students who enter engineering programmes have nine years of primary and secondary school and three years in upper secondary school (Swedish: Gymnasieskolan). Requirements for admittance are graduation from upper secondary school with special courses in mathematics, physics and chemistry. The students are admitted primarily based on their upper secondary school grades.

The Swedish programmes lead to a Master of Science degree in Engineering (Swedish: Civilingenjör). The nominal study time is 4.5 years. The average study time is, in actuality, about five years.

There are local variations in the programme structure of the participating Swedish programmes, but in general there are 2.5 years of compulsory course work and 1.5 years of elective course work within an in-depth profile. To obtain the final degree, each student has to complete a 20- week fulltime thesis project. This project is almost always carried out in cooperation with an industrial company and a university research group.

Postgraduate education in Sweden is nominally two or four years leading to licentiate or doctoral degrees, respectively.

The departments in Swedish universities are organized according to research disciplines and not undergraduate programme structure. The educational programmes covering courses from several different departments are formulated and monitored by independent programme boards, which comprise faculty, students, and, in many cases, industry representatives.

Royal Institute of Technology (KTH), the Vehicle Engineering Programme

KTH is a university of technology and science offering 17 engineering programmes and one architecture programme leading to Master of Science degrees. KTH has about 16 000 students in undergraduate programmes and 1600 postgraduate students.

Graduates of the Vehicle Engineering programme choose careers in the automotive, aeronautic, railway or ship industries as well as in companies requiring engineers with general applied mechanics and system technology skills. Approximately 125 students enter the programme each year. In the last 1.5 years, the students may primarily choose between nine in-depth profiles designed for the Vehicle Engineering programme, or they may choose from approximately 20 in-depth profiles available at the KTH School of Mechanical and Materials Engineering.

Linköping Institute of Technology (LiU), the Applied Physics and Electrical Engineering Programme

LiU is the engineering school of Linköping University. It offers 17 engineering programmes leading to a Master of Science degree. LiU has about 7000 students in undergraduate programmes and 600 postgraduate students.

The combined Applied Physics and Electrical Engineering Programme (the “Y-programme”) graduates students who choose careers in a broad spectrum of industrial fields, particularly electronics, computer engineering, software development, information technology, manufacturing, communications, processing industry and research institutes. Approximately180 students enter the programme each year. In their final 1.5 years, the students may choose among 11 in-depth profiles.

Chalmers University of Technology (Chalmers), the Mechanical Engineering Programme

Chalmers is a technical university offering 12 engineering programmes and one architecture programme, each leading to a Master of Science degree in the chosen area. Chalmers has about 7500 students in undergraduate (4.5-year) programmes and about 1050 postgraduate students.

Students graduating from the Mechanical Engineering programme could find occupations in a broad range of industrial areas. Most choose positions in manufacturing and design. Approximately 150 students enter the programme each year. In their final 1.5 years, the students may choose among 12 in-depth profiles.

USA University engineering programmes

Most USA students who enter USA engineering programmes have completed 12 years of primary and secondary school, often organized as eight years of primary school and four years of high school. Requirements for admittance vary among universities, but for engineering usually some advanced placement (i.e. beyond the normal high school curriculum) preparation in mathematics, physics and chemistry is necessary. The students are admitted on the basis of grades, standardized test scores, and, often, interviews.

USA engineering programmes lead to a Bachelor of Science degree in Engineering. The nominal study time is four years; however these four years include up to 25% study in humanities and social sciences — significantly more than in Swedish universities. The average study time is, in actuality, between 3.5 and five years. (The shorter study times are normally associated with private universities with higher tuition charges.)

There are many variations to the programme structure of USA engineering programmes, but, in general, there is a core of compulsory courses and additional elective subjects. These electives do not have the structure of the Swedish “profiles”, which bear rather more resemblance to courses at the USA Master level. Prior to graduation, students usually participate in an integrative capstone design subject. Some programmes require a Bachelor’s thesis.

USA university engineering departments are organized according to research disciplines, which are essentially synonymous with the undergraduate programme structure.

Massachusetts Institute of Technology (MIT), the Aeronautics and Astronautics Programme

MIT is primarily a science and technology university, offering multiple options for a Bachelor of Science degree through 11 engineering departments or divisions. MIT has about 4200 students in undergraduate programmes and 6000 postgraduate students. The postgraduate education leads to master and doctoral degrees.

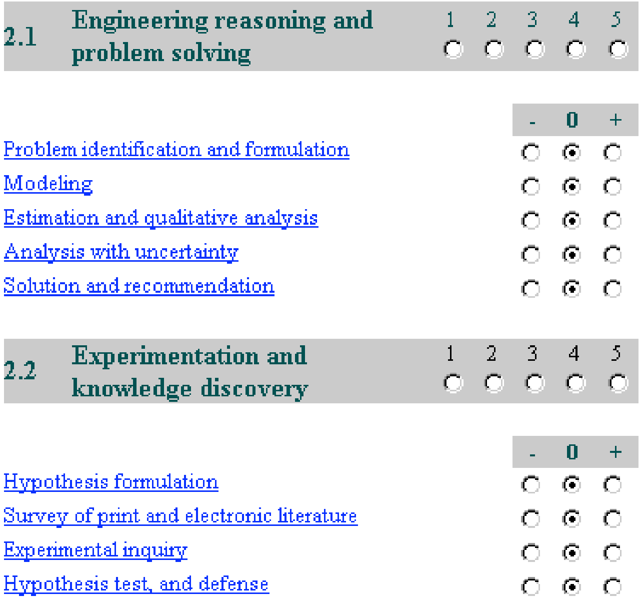
The Aeronautics and Astronautics programme at MIT reflects the breadth of disciplines necessary to work with modern aerospace systems, including vehicle, information and systems engineering. Approximately 70 students enter the programme each year. In their final two years, the students can chose between two degree options: one more centred on vehicle technology, or one focusing on embedded information technology. All students do an extensive laboratory project and a capstone design course prior to graduation.

Determining proficiency levels

To translate our list of topics and skills into learning objectives, we needed a process to determine the level of proficiency expected of graduating engineers in each of the Syllabus topics. This process must include stakeholder input and encourage consensus. This was achieved by creating a well-formulated survey, conducting the survey among appropriate stakeholder groups, and reflecting upon the result.

Formulating the survey

The first step in formulating the survey was the construction of a Web-based survey instrument. The graphic design of the survey is shown in Figure 3.



2.1	Engineering reasoning and problem solving	1	2	3	4	5
		○	○	○	○	○

	-	0	+
Problem identification and formulation	○	●	○
Modeling	○	●	○
Estimation and qualitative analysis	○	●	○
Analysis with uncertainty	○	●	○
Solution and recommendation	○	●	○

2.2	Experimentation and knowledge discovery	1	2	3	4	5
		○	○	○	○	○

	-	0	+
Hypothesis formulation	○	●	○
Survey of print and electronic literature	○	●	○
Experimental inquiry	○	●	○
Hypothesis test, and defense	○	●	○

Figure 3: Excerpt from the Web-based survey illustrating its graphic design.

The survey questionnaire was clear and concise and asked questions about the desired proficiency in such a way that information was collected for each topical Syllabus item. Each respondent was asked to rate "the expected level of proficiency of a graduating engineer" on a five–point activity–based scale (Table 2). The scale is intended to be absolute; for example, the most experienced engineers in practice would be able to "lead and innovate" in, for example, design. The expected proficiency on this scale can then be mapped to learning objectives expressed in any of several educational taxonomies. However, we found that in soliciting input from stakeholders, the simpler activity-based scale was more easily understood.

1	to have experienced or been exposed to
2	to be able to participate in and contribute to
3	to be able to understand and explain
4	to be skilled in the practise or implementation of
5	to be able to lead or innovate in

Table 2: Five point activity-based scale defining "the expected level of proficiency of a graduating engineer."

The survey concentrated on the second (X.X) and third level (X.X.X) categories of the CDIO Syllabus. For each set of attributes belonging to the second (X.X) level of the CDIO Syllabus the individual members of the survey groups were asked to indicate which of the five levels of proficiency they would expect of a that programme's graduates. They were also free to include a brief statement elaborating this level of proficiency.

For each X.X section, the survey groups were further asked to choose one or two topics for which the students should develop a "relatively higher" ("+") level of proficiency, and one or two for which they should develop a relatively lower ("-") level of proficiency in respect to that chosen for the X.X section. A relatively higher level is interpreted as one level higher on the five–point proficiency scale, and likewise for "one level" lower. It was further suggested, but not required, that the number of the relatively higher and relatively lower indications within any X.X section should balance.

The survey groups were also asked to divide 100 "Resource Points" among the X.X level CDIO sections. In this paper, only the X.X or second level expected proficiency results will be reported. The X.X.X level topical information is informative for detailed planning, but not essential to understand the main trends. The resource allocation data effectively mirrors the "expected proficiency" responses, and does not contain any significant new information.

Conducting the survey

The second step was conducting the survey. For each of the four programmes, we surveyed six groups. The first four comprised "professionals": faculty from within our universities; mid- to upper-level leaders of industry; recent alumni (about five years since graduation); and older alumni (about 15 years since graduation). The alumni groups were chosen so that the respondents were young enough to recall their education in some detail, yet old enough to be able to reflect on it with meaningful perspective. The two groups were selected to determine if the opinions of alumni changed with time. In addition, we surveyed first and fourth year students enrolled in the programmes to gauge how their expectations changed with experience, and how their opinions correlated with those of the professionals.

For each of the four programmes, the mean of the survey responses for each of the six stakeholder groups was calculated, and is presented in the Results and Analysis section below. Statistical tests (such as Student's t-Test) can determine if differences in the means are meaningful. The qualitative comments of the respondents were examined to determine if they led to any generalizable understanding of the trends and differences among different stakeholder groups.

The groups were told that surveys were being conducted at all four participating schools, but the surveys were designed so that each respondent group's expected level of proficiency would be specific to its program.

Results and analysis

Experience from data collection

The number of respondents in the survey groups at the four universities is shown in Table 3. The response rate was generally good. Although in a few cases the number of respondents was low, the total number of respondents in each demographic group is acceptable.

	Faculty	Industry leaders	5-year alumni	15-year alumni	First year students	Fourth year students
Chalmers	28	20	12	11	24	26
KTH	23	3	27	16	12	8
LiU	13	5	18	12	43	35
Swedish-Total	64	28	57	39	79	69
MIT	22	16	34	17	10	6
Total	86	44	91	56	89	75

Table 3: Number of respondents in each survey group at each university.

During processing of the survey data it was discovered that as a result of a software error, the Swedish universities' data for the topic Conceiving (4.3), were lost. Furthermore, it should be noted that as the issue of ability in foreign languages did not arise among the USA stakeholders, the topic Communications in Foreign Languages (3.3) was not included in the MIT survey.

Figure 4 shows the results of the survey for MIT professionals with the four respondent groups indicated. Note that only two statistically significant differences out of 78 (13x6) possible pair-wise comparisons performed using Student's t-Test occurred, both in the same section. Industry respondents did not feel graduating seniors need be as proficient at the design process as did the two alumni groups.

A study of Figure 4 indicates that in this comparison of expected proficiency, Engineering Reasoning and Problem Solving (2.1), Communications (3.2), Designing (4.4), and Personal Skills and Attitudes (2.4), with proficiency levels between 3.4 and 4, are the most highly ranked topics. Experts consistently cite these four topics as among the most important skills of engineering, and their high ranking is not a surprise. These correspond to an ability level four: "to be skilled in the practice" of these topics.

The Societal Context (4.1), the Enterprise and Business Context (4.2), Implementing (4.5) and Operating (4.6) are rated quite low, with proficiency near level two (corresponding to "an ability to contribute"). The low rankings in the Societal Context (4.1) and the Business Context (4.2) could not be explained through reading respondents comments. Respondents did specifically note that the low rankings on Implementing (4.5) and Operating (4.6) are because these topics may be better learned on the job, or may be too domain-specific to teach at a university.

Figure 5 shows the results of the survey for the Swedish professional respondents' groups. For each topic the average of the three Swedish universities is given. A statistical analysis using the Student's t-Test indicates that industry respondents do not believe a graduating senior should be as proficient in experimentation as do the other three professional survey groups. Furthermore, there are statistical indications that faculty respondents do not think a graduating engineer need be as proficient in systems thinking as do alumni respondents. Also, faculty do not rate teamwork proficiency as highly as do industry and 15-year alumni respondents.

The topics most highly ranked in the Swedish comparison of expected proficiencies are Engineering Reasoning and Problem Solving (2.1), System Thinking (2.3), Personal Skills and Attitudes (2.4), Teamwork (3.1), Communications (3.2) and Communications in Foreign Languages (3.3), all with average proficiency levels above 3.5. Compared to MIT, Designing (4.4) is missing, while System Thinking (2.3), Teamwork (3.1) and Communications in Foreign Languages (3.3) instead are included. It should be noted that any comparison made between MIT and the*Swedish universities might be affected by differences between English and Swedish interpretations of the CDIO Syllabus.

Societal Context (4.1), Business Context (4.2) and Operating (4.6) rate relatively low in the Swedish comparison, with average proficiency levels between 2.5 and 3, but not as low as in the MIT survey.

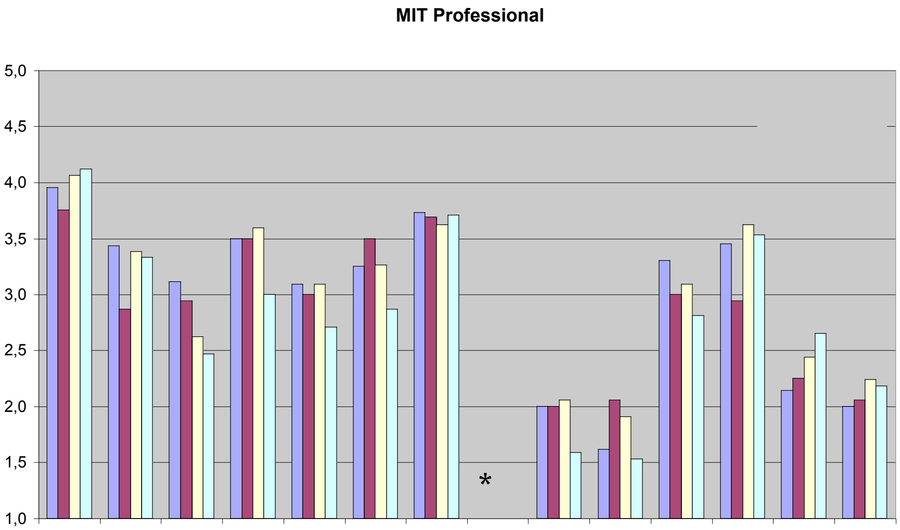


Figure 4: Levels of proficiency expected by MIT professionals surveyed.

*Area not included in survey

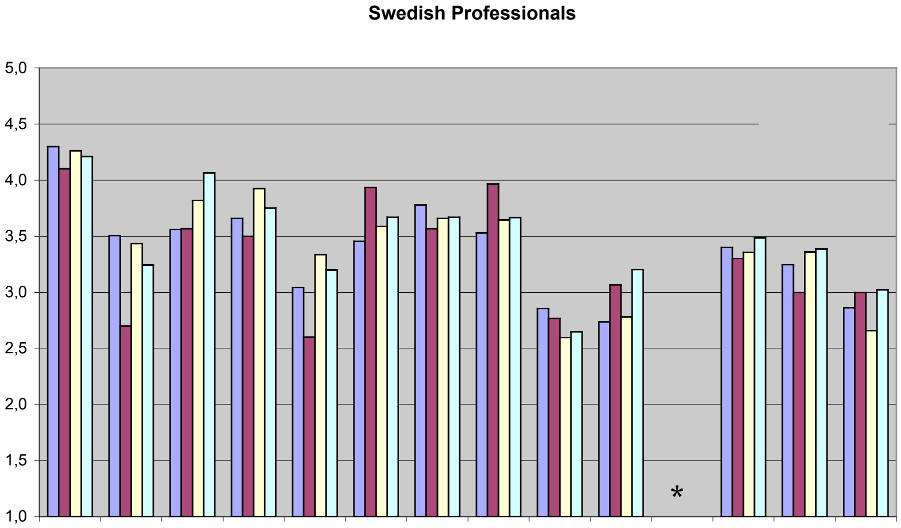


Figure 5: Levels of proficiency expected by Swedish professionals surveyed.
*Data missing due to software error.

A comparison of industry professionals' expectations of proficiency for the four universities' graduating engineers is shown in Figure 6. The quantitative agreement among the universities is, in general, very good for the topics in Level 2 and Level 3 of the CDIO Syllabus except for the Systems Thinking (2.3) where MIT respondents expect a proficiency level between 2 and 3, while LiU respondents expect a proficiency level above 4.

Major disagreements occur for the topics Societal Context (4.1), Business Context (4.2), Implementing (4.5) and Operating (4.6). The statistical analysis reveals some differences in the opinions among the Swedish respondent groups, particularly for Business Context (4.2) and Implementing (4.5), but the most significant difference is the considerably lower level of proficiency expected for topics 4.1, 4.2, 4.5 and 4.6, by the MIT respondent groups compared to the Swedish respondent groups. A possible explanation for this is that the Swedish universities are running 4.5-year programmes, while the programme at MIT is a four-year programme.

This is also a possible explanation for the differences among the results for the topics Societal Context (4.1), Business Context (4.2), Implementing (4.5) and Operating (4.6) for the Swedish and MIT industry respondents as shown in Figure 7. Another explanation is that these skills are trained in the required diploma thesis project that most Swedish engineering students carry out in industry under faculty supervision.

It should also be noted that Swedish respondents represented a wider range of engineering disciplines (vehicle, mechanical and applied physics/electrical), while MIT respondents were primarily drawn from aerospace professionals.

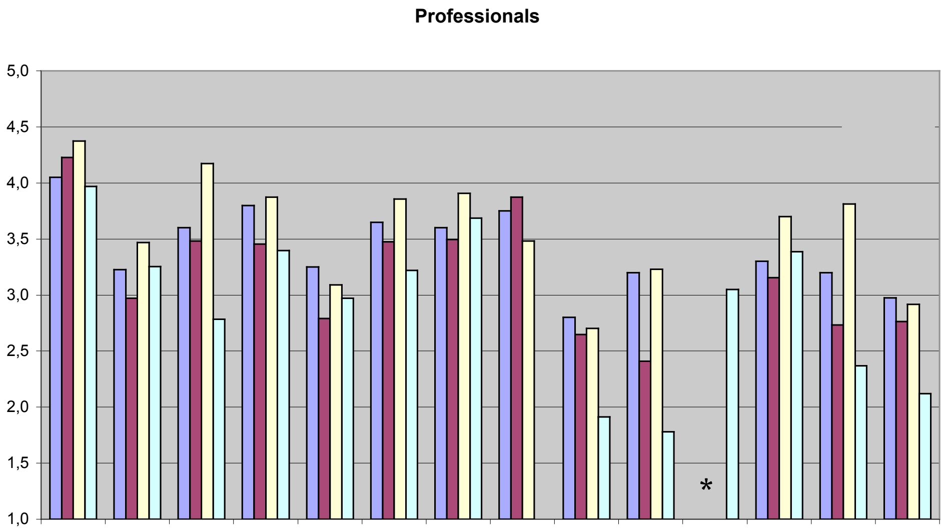


Figure 6: Average of professionals' expected levels of proficiency for graduating engineers at the four universities.

*Data missing due to software error.

A most significant result of the survey results, depicted in Figures 4 through 7, is the uncanny similarity of opinion among the groups. This degree of consensus was unexpected. It essentially confirms the desired level of proficiency we now expect in our graduating students. The differences expressed among the groups are probably smaller than the actual differences measurable in student proficiency.

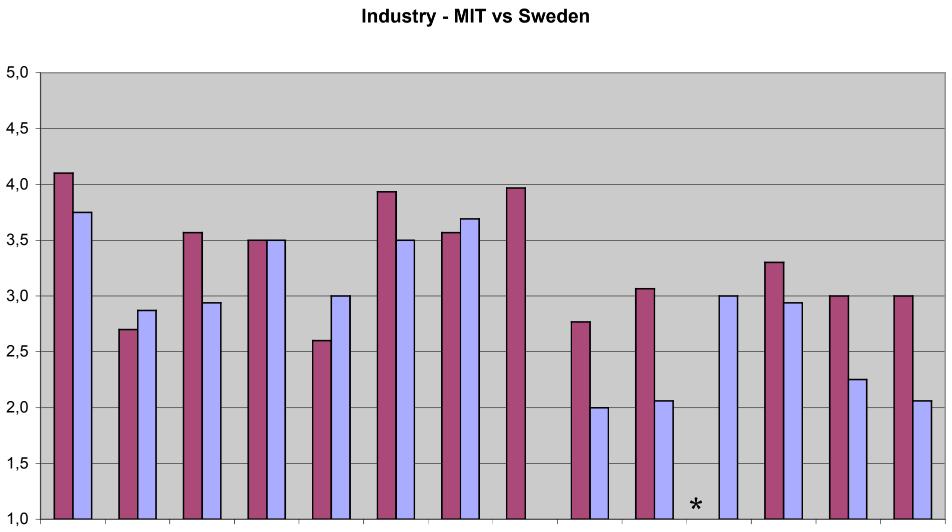


Figure 7: Average of levels of proficiency expected by Swedish and MIT industry leaders surveyed.

*Data missing due to software error.

Comparisons between professionals', and first and fourth year students' expectations of levels of proficiency for all four universities are shown in Figures 8 though 11. In analysing these results, the reader should keep in mind possible difficulties for first year students to understand all parts of the CDIO Syllabus due to their lack of experience.

There are a number of interesting observations that can be made from the results in Figures 8-11. The results in Figure 8 indicate that first year students at Chalmers expect less proficiency in Systems Thinking (2.3), Professional Attributes (2.5) and Implementing (4.5) than the professional respondents. It is also interesting to note the relative agreement, except for Systems Thinking (2.3), between the expectations of first and fourth year Chalmers students. The difference in the result for Systems Thinking may be due to the more experienced perspective of students in their final year.

The KTH results depicted in Figure 9 show many similarities with the Chalmers' results. It is interesting to note the low levels of proficiency expected by fourth year students in Engineering Reasoning and Problem Solving (2.1) and the Design Process (4.4), and the high-level of proficiency expected in Teamwork (3.1) by the first year students.

In Figure 10, the expected levels of proficiency by the first year students at LiU are considerably lower than those of both professionals and fourth year students in most topics. A possible reason for this is that the first year of LiU's Y-programme in is very heavy on mathematics, and unlike Chalmers, KTH and MIT students, the LiU students have not been introduced to product development and engineering early in their curriculum.

The results from MIT shown in Figure 11 reveal a trend opposite to the one at LiU. In most topics, the expected levels of proficiency of the students, and particularly the fourth year students, exceed those of the professionals. The might be explained by the observation that MIT students have been frequently exposed to the CDIO concept on numerous occasions.

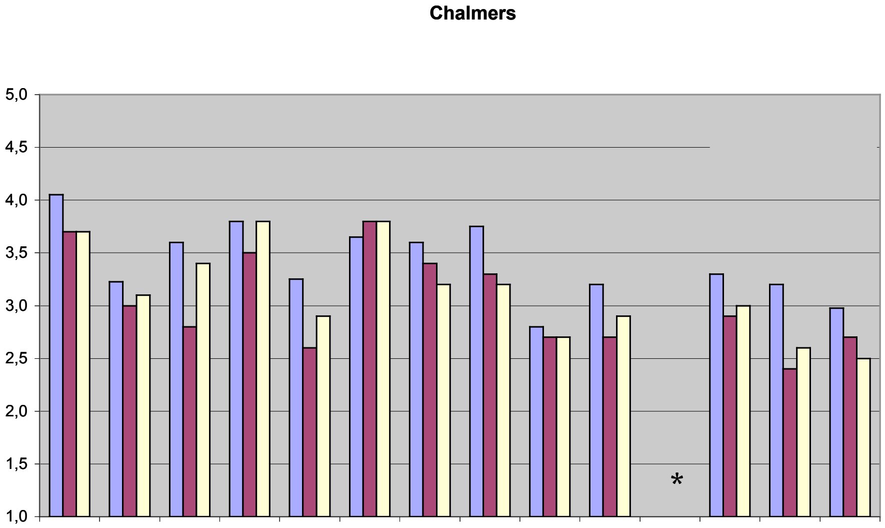


Figure 8: Average of professionals' expected levels of proficiency for first and fourth year Chalmers students.

*Data missing due to software error.

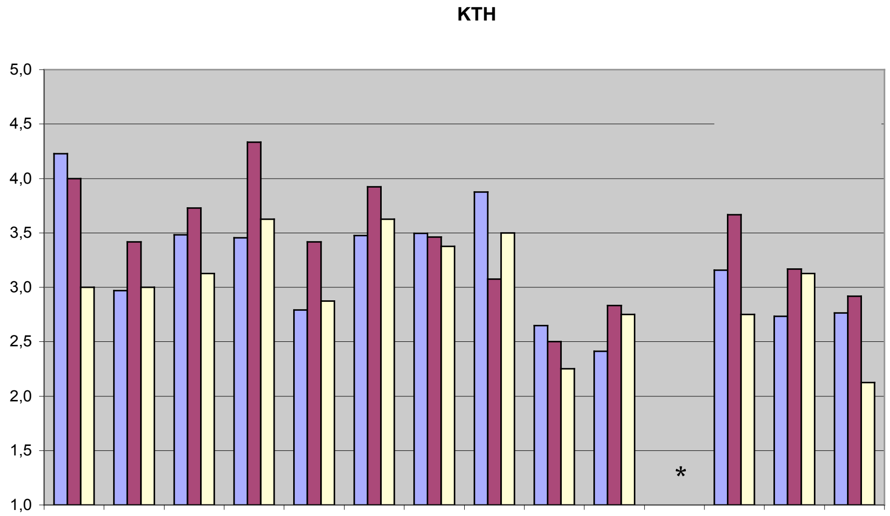


Figure 9: Average of professionals' expected levels of proficiency for first and fourth year KTH students.

*Data missing due to software error.

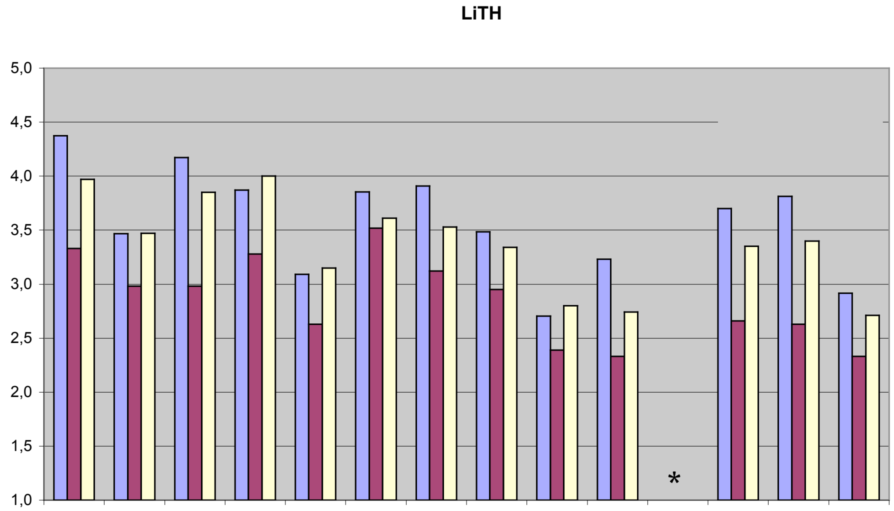


Figure 10: Average of professionals' expected levels of proficiency for first and fourth year LiU students.

*Data missing due to software error

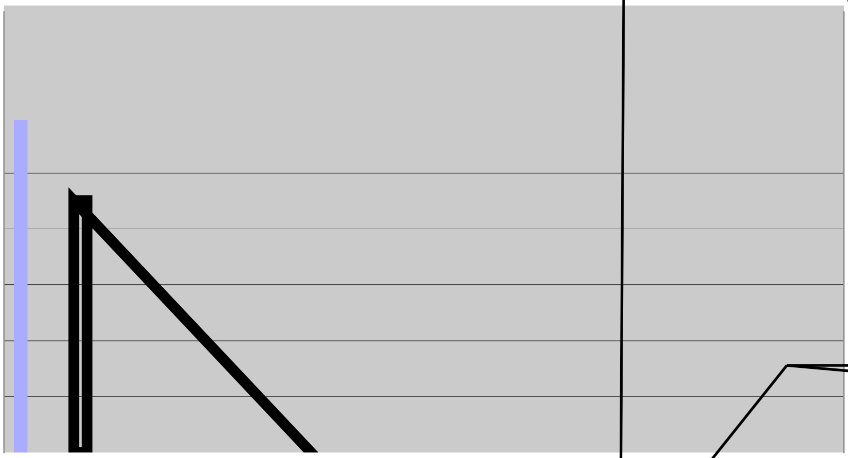


Figure 11: Average of professionals' expected levels of proficiency for first and fourth year MIT students

*Area not included in survey.

Summary and conclusions

Our conclusions and recommendations divide into three categories: those associated with the CDIO Syllabus as a generalized statement of goals, the process used in deriving specific versions for local programme needs, and the insights gained in comparing the customized syllabuses.

The CDIO Syllabus as a generalized statement of goals for undergraduate engineering education

We have attempted to derive a statement of goals for undergraduate engineering that has the following properties:

- It is rationalized against the modern practice of engineering, so the intent of the goals flows directly from the actual roles of engineers.
- It is comprehensive of all other high-level documents that attempt to outline the goals of engineering education.
- It is complete and consistent, in that all of the knowledge, skills, and attitudes that could be rationally expected to be possessed by a graduating engineer are included.
- It is presented sufficient detail that specific topics to be taught and learned are enumerated, laying the foundation for curriculum planning and outcome based assessment.
- It is linked to a survey process that will set levels of proficiency expected of a graduating engineer.

The Process for Deriving Specific Versions of the Syllabus for Local Programme Needs

Educational programmes seeking to use the CDIO Syllabus must adapt it to their specific discipline, needs and objectives. A suggested process of accomplishing this is as follows:

- Review the content of the topical Syllabus and add or delete topics based on the perceived needs of the particular programme. Changes in terminology might be needed to match the vernacular of the discipline, and some changes in organization at the third (X.X.X) level, or at the lowest level may be necessary as well.
- Identify the stakeholder communities, and conduct the surveys on expected proficiency at the second, or X.X, level, and at the third, or X.X.X, level, using the five-point proficiency scale stipulated.
- Compile the data from the two surveys, examine it for agreement and resolve any statistically significant disagreement among the stakeholders. Assign to each X.X.X level attribute a rating on the five-point proficiency scale described.
- Assign a level of proficiency for each low level topic in the form of the Syllabus. Use the survey data as guidance, but make choices that align with the context and local programme goals.

Insights gained in comparing the customized syllabuses

In comparing the syllabus survey results, we developed several important insights:

- The agreement among the faculty, leaders of industry, and young and mid-career alumni on the expected levels of proficiency of graduating engineers was significant and unexpected. In only a few cases were the differences statistically significant and qualitative. Even in these cases, the differences were modest and easily rationalized.
- The survey indicates that the skills for which the proficiency expectations are the highest include engineering reasoning, personal attributes, communications, and design. These four skills are consistently among those cited as most important in a young engineer. At the Swedish universities, the expected proficiency in Communications in Foreign Languages (3.3) also was high.
- The survey identified the social and enterprise context, implementing, and operating as requiring lower proficiency. This is likely due to the fact that these are more domain specific, and/or more appropriately acquired after graduation in a professional context.
- The detail in the Syllabus allows individual faculty to gain detailed insight into its content and objectives, contemplate the deployment of these skills into a curriculum, and prepare lesson and assessment plans.
- Adopting the CDIO Syllabus will facilitate more comprehensive and rigorous education in its topics, to the benefit of students who will enter the practice of engineering, and also to the benefit of those who will go on to be researchers.

- Widespread adoption of the Syllabus will also facilitate the sharing of best curricular and pedagogic approaches and it will promote the development of standardized assessment tools, which will allow easier and better outcome based assessment.
- All indications are that the CDIO Syllabus is adaptable to different languages, cultures and engineering professions.

We recognize that the Syllabus is a draft. We invite comments and feedback from those who study and apply it. Working together, the Syllabus will evolve into a more universal document, and shape the future of engineering education.

CDIO is an open architecture endeavor specifically designed for, and offered to, all university engineering programs to adapt to their specific needs. We are developing an open, accessible architecture for the programme materials, for disseminating and exchanging resources.

In designing and administrating CDIO, we reached beyond the traditional walls of engineering institutions to assemble a unique team of educational, design and build, and communications professionals. They are available to assist others to explore adopting CDIO in their institutions. Material available ranges from model surveys, to assessment tools, to reports from institutions that have implemented CDIO programs. Visit www.cdio.org for information.

Acknowledgement

The authors would like to acknowledge Mr Daniel Ahlman (KTH), Lt. Col. John E. Keesee and graduate students Raffi Babikian and Marshal Brenheizer (MIT) for valuable assistance in conducting the survey. They also gratefully acknowledge Mr William T. G. Litant (MIT) for editing the manuscript, and for his efficient handling of editorial issues generated by a group of authors from four universities in two countries.

References

---

[1] HAUG, G. AND TAUCH, C. (2001) Trends in Learning Structures in Higher Education (II). Follow-up Report prepared for the Salamanca and Prague Conferences

[2] Accreditation Board for Engineering and Technology, Engineering Criteria 2000, Baltimore, MD, 1994. Available at http://www.abet.org

[3] BRODEUR, D.R., E.F. CRAWLEY, I. INGEMARSSON, J. MALMQVIST, and S. OSTLUND, "International Collaboration in the Reform of Engineering Education", Proceedings of the 2002 American Society for Engineering Education Annual Conference and Exposition, Montreal, Canada, June 16-19, 2002. Available at http://www.asee.org/conferences/proceedings/search.cfm

[4] ASEE Engineering Deans Council Corporate Roundtable, Engineering Education for a Changing World, Washington, DC, American Society for Engineering Education,1994.

[5] SUTHERLAND, T.E., and C.C. BONWELL, eds., "Using Active Learning in College Classes: A Range of Options for Faculty", *New Directions for Teaching and Learning,* No. 67, San Francisco, CA, Jossey-Bass, 1996.

---

[6] HALL, S.R., I. WAITZ, D. R. BRODEUR, D. H. SODERHOLM, and R. NASR, "Adoption of Active Learning in a Lecture-Based Engineering Class", 32nd ASEE/IEEE Frontiers in Education Conference, Boston, Massachusetts, 06-09 November 2002.

[7] BRODEUR, D.R., P.W. YOUNG, and K.B. BLAIR, Problem-Based Learning in Aerospace Engineering Education, Proceedings of the 2002 American Society for Engineering Education Annual Conference and Exposition, Montreal, Canada, 16-19 June 2002. Available at http://www.asee.org/conferences/proceedings/search.cfm

[8] HUBA, M.E., and J.E. FREED, Learner-Centered Assessment on College Campuses, Boston, Massachusetts, Allyn and Baron, 2000.

[9] PALOMBA, C.A., and T.W. BANTA, Assessment Essentials: Planning, Implementation, and Improving Assessment for Higher Education, San Francisco, California, Jossey-Bass, 1999.

[10] CRAWLEY, E.F., The CDIO Syllabus – A Statement of Goals for Undergraduate Engineering Education, Cambridge, Massachusetts, Massachusetts Institute of Technology, Department of Aeronautics and Astronautics, 2001.

[11] The Boeing Company, Desired Attributes of an Engineer: Participation with Universities, 1996. Available at http://www.boeing.com