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A CDIO-BASED COMPARISON OF ENGINEERING CURRICULA IN THE USA, CANADA, SWEDEN AND THE UK

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ABSTRACT

Having introduced the CDIO Syllabus and the CDIO Standards, the authors review some of the factors that have influenced the development of engineering education in the USA, Canada, Sweden and the UK. Representative engineering programmes from each country are then used to illustrate that there are national differences in engineering curricula. As a consequence it is necessary to examine the implications for meeting the requirements of the CDIO Syllabus. It is also important to determine if there is conflict between the CDIO Syllabus and national accreditation criteria. The authors discuss how national differences can be catered for, and argue that there is no conflict with current accreditation criteria. As a result it is suggested that the CDIO Syllabus, coupled with the CDIO Standards, can form the basis of international requirements for engineering education. Such requirements would be aspirational, and hence complementary to the minimum or threshold requirements that are emerging in the form of global accreditation criteria.

1. INTRODUCTION

The collaborators in the CDIO Initiative have developed an approach to reforming engineering education which is based on two main elements; the CDIO Syllabus and the CDIO Standards [1]. The CDIO Syllabus is an organized list of the areas of knowledge, skills and attributes that an engineering graduate could reasonably be expected to possess. It is intended to be generic, in the sense that it is independent of both the country and the engineering discipline involved. The main sections of the CDIO Syllabus are listed in Table 1. It has two further levels of detail, one of which is shown in the version which appears in Appendix A. Although the Syllabus is presented as a list of topics, it is intended to be the source of student learning outcomes for a programme. However, stakeholders in the programme are first surveyed to establish the level of proficiency that students should achieve in the listed topics, before programme learning outcomes are defined [2].

The CDIO Standards focus primarily on the delivery of an engineering programme, rather than its content. They address the context for student learning, the design of the curriculum, the teaching, learning and assessment methods used, the need to upgrade faculty skills and the importance of continuous improvement in engineering education. The 12 CDIO Standards are listed in Table 2, and brief explanations are provided in Appendix A.

Table 1: The Main Sections of the CDIO Syllabus

CDIO SYLLABUS	
1	**Technical Knowledge**
2	**Personal and Professional Skills**
2.1	Engineering Reasoning and Problem Solving
2.2	Experimentation and Knowledge Discovery
2.3	System Thinking
2.4	Personal Skills and Attributes
2.5	Professional Skills and Attitudes
3	**Interpersonal Skills**
3.1	Teamwork and Leadership
3.2	Communication
3.3	Communication in Foreign Languages
4	**Product and System Building Knowledge and Skills**
4.1	External and Societal Context
4.2	Enterprise and Business Context
4.3	Conceiving
4.4	Designing
4.5	Implementing
4.6	Operating

Table 2: Titles of the CDIO Standards

CDIO STANDARDS	
1	CDIO as Context
2	CDIO Syllabus Outcomes
3	Integrated Curriculum
4	Introduction to Engineering
5	Design-Build Experiences
6	CDIO Workspaces
7	Integrated Learning Experiences
8	Active Learning
9	Enhancement of Faculty CDIO Skills
10	Enhancement of Faculty Teaching Skills
11	CDIO Skills Assessment
12	CDIO Program Evaluation

The main purpose of this paper is to assess the extent to which national circumstances affect the ability of engineering programmes to meet the requirements of the CDIO Syllabus. Initially the assessment is based on an overview of the characteristics of engineering education in four of the countries participating in the CDIO Initiative; the USA, Canada, Sweden and the UK. Specific examples of engineering programmes in each country are then analysed, both to illustrate the national differences that exist, and to examine the implications for the CDIO Initiative. The possibility of conflict between national accreditation criteria and the requirements of the CDIO Syllabus is also assessed. The discussion which follows leads to a proposal whereby CDIO requirements would co-exist with accreditation criteria as an international standard that engineering programmes would seek to achieve.

2. ENGINEERING EDUCATION IN THE USA, CANADA, SWEDEN AND THE UK

Engineering degree programmes vary from country to country because of a variety of factors. Differences in education systems mean that the knowledge and experience of students entering university is not consistent around the world. The structure and length of degree programmes also varies, and engineering programmes differ for historical reasons and as a result of national initiatives to promote change. In addition, national quality assurance systems and the criteria used to accredit engineering programmes tend to be unique to the country involved.

Of the four countries considered in this study, the USA, Canada and Sweden have education systems where students receive a relatively broad education before entering university. In Sweden's case there is some streaming at the upper secondary level, with potential university entrants completing either a natural science programme or a social science programme. The UK differs from the others because students entering university will have spent two years studying a limited number of subjects in some depth, for which they are awarded "A Levels". Traditionally entry to engineering schools has required A Levels in mathematics and physics. This means that engineering science can be taught from the first year, on the basis of prior learning in the underlying subjects.

Four year engineering programmes are the norm in the USA and Canada. In recent years Sweden has offered both 3 year bachelors programmes and 4½ year masters programmes. The UK also offers 3 year bachelors programmes, but only one additional year is required for a masters degree. However the Bologna Declaration signed by most European countries in 1999 calls for a 3 year bachelors cycle and a 5 year masters cycle, which Sweden is responded to, but the UK is likely to resist.

The history of engineering education in the USA, and to some extent Canada, is well documented [3]. The theoretical basis for engineering was developed in Europe during the 19th century, but only became a significant influence on American engineering education in the period after World War I, when leading European academics settled in the USA [4]. "Even so, through the 1940s, engineering remained, at most institutions, a highly practical subject, with little application of mathematics beyond elementary calculus" [5]. However, a transformation occurred after World War II, in part because physicists rather than engineers were responsible for most major wartime developments [6]. This was attributed to insufficient science and mathematics in the engineering curriculum. Along with the substantial research funding that became available to engineering schools as a consequence of the Cold War, this led to "a paradigm shift from an applied, practical focus to a mathematical, engineering science focus" [5] in engineering education in the USA during the 1950s. The process of moderating this paradigm shift started in the USA in the late 1980s, and the CDIO Initiative represents a contemporary approach that seeks to achieve a better balance, while ensuring that engineering graduates have the skills and aptitudes they require.

The changes in engineering education referred to above were less dramatic in the case of the UK, as research spending triggered by the Cold War was not as significant a factor. The main requirement was to rebuild the economy after World War II. By the mid 1970s it was argued that the priority was for engineering graduates who would work effectively in manufacturing companies, where they would need a basic knowledge of subjects such as accountancy, industrial relations and management. This led to the so-called "Dainton Initiative", that ultimately produced the UK's 4 year masters programmes. From the outset the masters programmes included "Professional Studies" courses designed to cover industrially-relevant subjects. The 1980s saw further initiatives aimed at increasing the emphasis in engineering education on "applications" and design. However the 1980s also saw the introduction of the first national Research Assessment Exercise (RAE) in the UK. This involved, and has continued to involve, the periodic rating of individual schools in all UK universities on the basis of the quality of their research. The results determine a proportion of the funding that schools, and hence universities, receive from central government. The impact has been to concentrate teaching expertise on engineering science subjects, because academic recruitment tends to favour those with research potential. As a result it has been difficult for engineering schools in the UK to move away from engineering science based curricula.

Of the countries considered in this study, the USA, Canada and the UK have accreditation systems for engineering education. Accreditation in the USA dates back to 1932, and over the ensuing decades the tendency was for accreditation criteria to become more detailed and prescriptive. However there was a major change in direction when ABET introduced the current EC2000 accreditation criteria [7], which focus primarily on student learning outcomes. Specifically it is stated that engineering programmes 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 within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability

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 responsibilities

g) an ability to communicate effectively

h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, 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

EC2000 also includes some general requirements, such as the need for 1½ years of engineering science and design, and the need to include a major design experience in the curriculum. In addition, essential subjects are listed for specific engineering disciplines. However curriculum content is not overly prescribed, and the traditional requirement that half a year or more must be devoted to the humanities, arts and social sciences (HASS) no longer applies. Instead programmes merely have to include "a general education component" with no minimum time specified.

In the UK, accreditation was first introduced in the 1960s, and the criteria became increasing prescriptive, as they had in the USA. However the same change in approach to outcomes-based criteria occurred with the publication of UK-SPEC in 2004 [9]. The main headings of the learning outcomes listed in UK-SPEC are:

A. General Learning Outcomes

1. Knowledge and Understanding
2. Intellectual Abilities
3. Practical Skills
4. General Transferable Skills

B. Specific Learning Outcomes

1. Underpinning Science and Mathematics, and associated Engineering Disciplines.
2. Engineering Analysis
3. Design
4. Economic, Social and Environmental Context
5. Engineering Practice

For an MEng programme, UK-SPEC lists 55 different learning outcomes under the above headings [8], which is significantly more than ABET's 11 outcomes. UK-SPEC was produced by the UK Engineering Council, but individual professional institutions are responsible for accrediting degree programmes in the UK. Each institution generally publishes its own discipline-specific criteria to supplement the Engineering Council criteria. Hence according to the Institution of Mechanical Engineers, for example, the curriculum should contain business and management subjects and MEng students must undertake both an individual project and a team-based project.

The Canadian Engineering Accreditation Board (CEAB), which was formed in 1965, is responsible for accrediting programmes in Canada [9]. In contrast to the USA and the UK, the CEAB has retained accreditation criteria based on curriculum content, and has not made the transition to outcomes-based criteria. Hence minimum requirements are set for the time devoted to mathematics, basic science, engineering science, engineering design and "Complementary Studies". The latter covers the HASS subjects traditionally required in the USA, plus management, engineering economics and communication skills. The CEAB also specify particular topics in mathematics along with required science and engineering science subjects. The accreditation criteria consciously leave a modest number of curriculum hours to the school's discretion, so that it may "demonstrate innovation". Despite this, it is clear that engineering schools in Canada have much less freedom than their counterparts in the USA and the UK to plan the structure and content of the curriculum.

Sweden does not have an accreditation system for engineering programmes. However, a national programme for quality assurance was introduced in 2001 to evaluate degree programmes in all disciplines [10]. This is operated by the National Agency for Higher Education which reports to the Swedish Ministry of Education. The evaluation process is not prescriptive, and relies on significant input from stakeholders including student opinion. It is of note, however, that the national agency recently adopted the CDIO Standards as an instrument for self-improvement in engineering education. The intention is that programmes will be self-rated against the CDIO Standards, and actions identified to increase the rating and hence improve the programme. A survey of programme managers has been undertaken to assess the applicability of the CDIO Standards [11]. The results showed some concerns with Standard 1, which assumes that graduates will be involved in conceiving, design, implementing and operating value-add products and systems. It was also felt that rating against the CDIO Standards did not acknowledge a programme's weaknesses or strengths in the teaching of disciplinary knowledge. Despite these reservations, adoption of the Standards for programme evaluation highlights the fact that there are matters related to pedagogy, curriculum structure and programme context that affect the student learning experience, but are not normally assessed as part of the accreditation process.

With increasing globalization and the need to ensure the international mobility of engineers, it is not surprising that quality assurance and accreditation are developing an international dimension. To date, the main developments have centred on mutual recognition agreements, most notably the Washington Accord [12]. This was signed by a number of countries in 1989, including the USA, Canada and the UK, who agreed that they would respect each other's accreditation criteria. In a more recent development Europe-wide accreditation criteria were published for engineering programmes. The EUR-ACE project reviewed accreditation procedures in 19 European countries and generic European criteria were published in 2005, in the form of a set of agreed learning outcomes [13]. There are 39 learning outcomes listed for a masters cycle programme, and they bear some similarity to the UK-SPEC criteria. However, they are noticeably less specific, which is the inevitable result of compromise to obtain international agreement on minimum accreditation criteria. Developments are also occurring outside Europe to move towards agreed international criteria, rather than mutual recognition agreements, and the expectation is that a global accreditation system will eventually emerge [14].

3. AN ANALYSIS OF REPRESENTATIVE PROGRAMMES

Individual engineering programmes are analysed in this section in order to illustrate how the influences discussed above have led to differences in curriculum structure and content in the USA, Canada, Sweden and the UK. The analysis also seeks to identify the implications of national differences in terms of meeting the requirements of the CDIO Syllabus. The specific programmes involved the study are the following:

1. Chalmers University of Technology (**CHA**), Göteborg, Sweden - Mechanical Engineering.
2. Queen's University, Kingston, Canada (**QUC**) - Mechanical and Materials Engineering.
3. Queen's University, Belfast, UK (**QUB**) - Mechanical and Manufacturing Engineering.
4. Linköping University, Sweden (**LIU**) - Applied Physics and Electrical Engineering.
5. Massachusetts Institute of Technology, USA (**MIT**) - Aeronautics and Astronautics.

For reference, a year-by-year listing of the courses offered in each of the above programmes appears in Appendix B. (The listing only covers the first four years in the case of the two Swedish programmes.) For comparison, the analysis assigned individual courses in each programme to one or more of the main sections of the CDIO Syllabus. The total timetabled hours or student credits associated with each section was then converted to a percentage of the total available, and the results are shown in Table 3.

Table 3: Percentage of Curriculum devoted to Sections of CDIO Syllabus

	Mechanical Engineering Based					
	CHA	**QUC**	**QUB**	**LIU**	**MIT**	**MIT- 1**
SYLLABUS SECTION	%	%	%	%	%	%
1.1.1 Mathematics	15.5	12.0	5.2	29.7	12.1	16.0
1.1.2 - 4 Underlying Science	16.3	14.8	2.1	12.5	12.1	16.0
1.2 Core Engineering Knowledge	13.6	27.6	31.3	11.3	20.0	26.4
1.3 Adv. Engineering Knowledge	11.8	10.4	16.7	19.4	13.0	17.1
1. Maths, Science & Engng	**57.2**	**64.7**	**55.2**	**72.8**	**57.3**	**75.6**
2. Personal & Professional Skills	**7.6**	**3.4**	**4.8**	**7.2**	**3.7**	**4.9**
3. Interpersonal Skills	**2.3**	**3.0**	**2.5**	**3.4**	**3.7**	**4.9**
4.1 External & Societal Context	7.9	5.4	3.1	1.9	0.1	0.1
4.2 Enterprise & Business Context	8.1	1.7	5.2	1.9	0.0	0.0
4.3 Conceiving	2.7	5.4	2.1	2.5	1.7	2.3
4.4 Designing	6.8	11.4	14.6	4.7	5.8	7.6
4.5 Implementing	4.8	3.8	8.3	4.7	2.5	3.3
4.6 Operating	2.7	1.2	4.2	0.9	1.0	1.3
4. Product / System Building	**32.9**	**28.9**	**37.5**	**16.6**	**11.1**	**14.7**
Total Project Work	**19.8**	**10.1**	**12.5**	**11.1**	**11.3**	**14.9**
Other					**24.2**	

In the case of Sections 1 and 4 of the Syllabus, cumulative totals are shown in the bold rows. It should be stressed that in Table 3 individual courses were assigned to the section or sections of the CDIO Syllabus that reflect their primary aim. Hence an underlying science course may include a team-based assignment or a project or may incorporate the teaching of a personal skill, but all of the course hours or credits were assigned to Underlying Science. This approach was adopted so that the table would highlight the challenges involved in covering the CDIO Curriculum, and the need for innovative ways of meeting these challenges. Stand-alone projects, such as capstone projects, need a different approach, since they are not normally associated with a particular section of the CDIO Syllabus. Hence for projects only, the course hours or credits were distributed among a number of sections, such as Personal and Professional Skills, Interpersonal Skills, Conceiving, Designing etc., depending on the nature of the project. An additional row is included in the table to separately record the Total Project Work. A row entitled Other is also shown in order to record the HASS component in the MIT programme, although part of the content could have been assigned to particular sections of the Syllabus, principally the External and Societal Context. The HASS component tends to distort the MIT figures; hence a second column is shown for the MIT programme (MIT-1), where the percentages do not include the HASS component.

An examination of the data in Table 3, supported by the information in Appendix B, leads to the following observations:

- The fact that UK students specialize before entering university significantly reduces the need to teach Mathematics and Underlying Science.

- Almost 30% of the Linköping programme, which is in Applied Physics and Electrical Engineering, is devoted to teaching Mathematics.

- The HASS component in the MIT programme significantly reduces the time available to cover the CDIO Syllabus, although project work still features strongly in the curriculum.

- Different approaches are evident in the case of the External and Societal Context. The Chalmers programme includes a course on Environmental and Energy Systems and Linköping offer Man, Technology and Society. MIT address this section within their capstone projects, and the percentage shown could be increased by adding a contribution from the HASS component. Queen’s (Canada) provide some coverage through their Complementary Studies courses, and Queen’s (UK) do the same through their Professional Studies courses (which have remained part of the curriculum since their introduction in the 1970s). However the Professional Studies courses focus mainly on health and safety and the legal obligations of professional engineers.

- The Enterprise and Business Context is also dealt with by MIT in their capstone projects. However the other programmes feature courses that directly address this section of the CDIO Syllabus. Queen’s (UK) again use their Professional Studies courses to cover a range of subjects including Economics, Accountancy, Marketing and Management. The remaining three programmes provide courses on Economics.

- Designing is generally covered through project work, but the Mechanical Engineering programmes at Chalmers, Queen’s (Canada) and Queen’s (UK) feature courses specifically devoted to design. The Queen’s (Canada) programme includes courses on Design Techniques and Machine Design and Engineering Design is taught in each of the first three years at Queen’s (UK).

- Implementing also tends to receive more attention in the Mechanical Engineering programmes, through courses dealing with manufacturing systems and processes. The presence of dedicated courses in both design and manufacturing in the

Mechanical Engineering programmes results in the high percentages shown in Table 3 for Product / System Building knowledge and skills.

- Operating can have different meanings depending on the context. The Queen's (UK) programme has the highest percentage for this section because the degree awarded is in Mechanical and Manufacturing Engineering. Hence courses are included in Production Management and Quality Systems, which address the manufacturing engineer's interest in the operation of manufacturing systems.

4. MEETING THE REQUIREMENTS OF THE CDIO SYLLABUS

The analysis presented above illustrates how national differences influence and constrain the curriculum. In the case of the MIT programme the need to teach fundamental mathematics and the underlying sciences, plus the time allocated to the HASS component, leave little scope for addressing sections of the CDIO Syllabus directly through dedicated courses. In contrast, Queen's (UK) does not have to cater for either requirement, and has the advantage that the curriculum includes Professional Studies courses. Hence there is more time available and more opportunities exist to provide dedicated courses on a range of Syllabus topics. Queen's (Canada) has to deal with restrictive accreditation criteria, but the criteria do at least allow part of the curriculum to be devoted to Complementary Studies, which means that curriculum time can be assigned to non-technical subjects. In the absence of accreditation constraints, the Swedish programmes include courses targeted at specific subjects concerned with the external, societal, enterprise or business context. The fact that there will be a full fifth year in the Swedish programmes could also create opportunities for dedicated courses on Syllabus topics. However, the practice in Sweden of providing students with a wide range of elective courses in the later years means that such courses have to be included in the first three years.

It is also apparent from the above analysis that the engineering discipline involved has a major influence on the extent to which a programme currently covers the CDIO Syllabus. In particular, Mechanical Engineering based programmes tend to automatically include subjects that contribute to the Syllabus sections on Designing, Implementing and possibly Operating. In the case of other disciplines, typified by the Linköping programme, the theoretical nature of the subject matter requires an extensive grounding in mathematics, thus reducing the time available to address CDIO Syllabus topics.

When it is possible to provide dedicated courses on CDIO Syllabus topics, the evidence of the above analysis suggests that the focus of the courses is sometimes relatively narrow. The examples quoted above of courses dealing with the External and Societal Context and the Enterprise and Business Context illustrate this point. There may therefore be some benefit in considering how dedicated courses can be designed that would more fully address particular sections of the CDIO Syllabus. It is noted that there are no courses in the programmes considered with the title "The External and Societal Context" or "The Enterprise and Business Context", but it is not inconceivable that courses with such titles could be devised.

In cases where there are limited opportunities for dedicated courses, other ways of covering the topics in the CDIO Syllabus have to be found. It is also evident that, due to the comprehensive nature of the CDIO Syllabus, full coverage through dedicated courses is not a viable proposition. In fact the CDIO Standards provide an alternative. CDIO Standard 7 calls for "integrated learning experiences" that address topics in the CDIO Syllabus within existing disciplinary courses i.e. courses in mathematical, scientific and engineering subjects. In effect, a "dual use of time" approach is advocated, which can reduce the need for dedicated courses. The development of Instructor Resource Modules (IRMs) within the CDIO Initiative is designed to provide support for faculty who adopt this approach. The dual use of time approach has already been adopted within the programmes at MIT and the Swedish universities (although this is not reflected in the data presented in Table 3). The use of disciplinary courses in this way has other advantages, including the fact that students are acquiring knowledge or skills within the context of a disciplinary subject.

In Table 3, the curriculum time devoted to project work was assigned to various sections of the CDIO Syllabus. This serves as a reminder that projects provide the most obvious opportunity to address a variety of Syllabus topics. Apart from product and system building skills, a wide range of personal, professional and interpersonal skills can be developed in well-conceived projects. Students can also gain a greater awareness of external, societal, enterprise and business issues in broadly based projects that are not restricted to technical issues. It would be a worthwhile exercise to examine different types of project, with a view to developing a model for a “CDIO project” that was designed to maximize its coverage of topics in the CDIO Syllabus.

The analysis of a number of representative programmes has led to a discussion of ways in which a programme can meet the requirements of the CDIO Syllabus. Three approaches have been highlighted; providing appropriate dedicated courses, creating integrated learning experiences within disciplinary courses, and more fully exploiting project work in order to maximize coverage of the CDIO Syllabus. In a particular case, all three approaches will inevitably be used to address the comprehensive list of topics in the Syllabus. However, as the analysis has also shown, the extent to which each approach is employed, and the topics that each approach is used to address, will depend on both national factors and the specific discipline involved.

5. ACCREDITATION AND THE CDIO REQUIREMENTS

As discussed in Section 2, Sweden does not have an accreditation system, while in the USA, Canada and the UK different accreditation criteria apply. Satisfying accreditation criteria naturally takes precedence over meeting the needs of the CDIO Syllabus. Hence there is a potential problem in the USA, Canada and the UK when it comes to satisfying the CDIO requirements. In the case of Canada, the prescriptive constraints on curriculum content may reduce the scope for covering the CDIO Syllabus, but in the absence of required learning outcomes there is no conflict between accreditation and the CDIO Syllabus. However, conflict is possible in the USA and the UK, where programmes will have to deliver two different sets of learning outcomes. However close examination reveals that the problem does not arise, because the topics listed in the CDIO Syllabus adequately cover all of the learning outcomes required by ABET or UK-SPEC. However it is also evident that in each case the CDIO Syllabus includes topics that do not feature in the accreditation criteria. The EC2000 learning outcomes, for example, make no overt reference to the enterprise and business context, apart from its economic aspects. Importantly the CDIO Syllabus also adds significant detail to the EC2000 outcomes. UK-SPEC lacks coverage of experimentation and knowledge discovery i.e. research skills, and omits important personal and professional attributes. In addition both sets of accreditation criteria focus on design as the main area of engineering practice, and there is a lack of recognition that engineers are engaged in all stages in the lifecycle of products and systems.

It is important to acknowledge that there is a fundamental difference between accreditation criteria and the CDIO requirements. The purpose of accreditation is to ensure that engineering programmes meet a minimum standard, and hence accreditation criteria are threshold criteria. In contrast, the CDIO requirements represent a higher standard that the CDIO collaborators believe is possible in engineering education. No programme currently covers all of the topics in the CDIO Syllabus, but full coverage should be a goal, and in this sense the CDIO requirements are aspirational. It is therefore clear that the CDIO requirements and accreditation criteria are complementary, since there is no incompatibility between meeting minimum requirements and aspiring to a higher standard.

At present accreditation requirements are set by national bodies, but as already discussed progress is expected towards global accreditation in the coming years. The international accreditation criteria that will evolve will undoubtedly be less stringent than current national criteria, as evidenced by the EUR-ACE requirements. Hence it will arguably be more important to have complementary international criteria that represent a higher standard for engineering education to aspire to. The CDIO requirements can fulfil this role, as they are the product of international collaboration and are applicable internationally, based on the evidence and arguments presented in this paper.

Adoption of the CDIO Standards in Sweden as a possible tool for continuous improvement is an interesting development. Quality assurance agencies involved in accreditation have tended to avoid pronouncements on pedagogical issues. Yet it is clear that the quality of an engineering programme depends on factors such as the teaching, learning and assessment methods used, and whether or not the curriculum is designed to support student learning. It could therefore be argued that enhanced international requirements, of the type proposed above, should be based on both the CDIO Syllabus and the CDIO Standards. Again the requirements would be aspirational, and the CDIO Syllabus as well as the CDIO Standards would be employed to monitor progress, in the same way that the Standards are currently being used by Swedish National Agency for Higher Education. However, as the debate in Sweden suggests, further "field testing" of the Standards, and also the Syllabus, should first be considered within the CDIO Initiative.

6. CONCLUSIONS

Differences in education systems, historical events and quality assurance practices have led to differences in the way that engineering education has developed in the USA, Canada, Sweden and the UK. An analysis of representative programmes has illustrated how this translates into differences in engineering curricula. Analysing curriculum content in terms of which sections of the CDIO Syllabus it addresses has shown that programmes vary in the extent to which they already cover Syllabus topics within dedicated courses. Other approaches are needed and topics can be dealt with by embedding them in disciplinary courses as integrated learning experiences. A third possibility is to exploit project work more fully as a vehicle for addressing topics in the Syllabus. In practice all three approaches will be employed, but the strategy adopted in terms of which approach is used for a particular Syllabus topic, will depend on national characteristics and the particular discipline involved. It would be useful to extend the comparison presented in Table 3 to include additional programmes, with a view to developing alternative strategies for addressing the requirements of the CDIO Syllabus, that take national characteristics and the discipline involved into account.

The authors have considered whether adherence to the CDIO Syllabus conflicts with accreditation criteria. However, close examination shows that the CDIO Syllabus exceeds the national criteria in the case of both the USA and the UK. It has therefore been suggested that the CDIO Syllabus could be regarded as the basis for a higher international standard that engineering education would aspire to. Meeting the CDIO Standards should also be a requirement. Although further validation may be necessary, the CDIO Syllabus and Standards would together form aspirational requirements for engineering education, which would complement the baseline requirements likely to emerge in the form of global accreditation criteria.

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APPENDIX A: THE CDIO SYLLABUS AND STANDARDS

THE CDIO SYLLABUS

1 TECHNICAL KNOWLEDGE AND REASONING

- **1.1 Knowledge of underlying sciences -** Mathematics (including statistics). Physics. Chemistry. Biology
- **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 -** *Problem Identification and Formulation. Modeling. Estimation and Qualitative Analysis. Analysis With Uncertainty. Solution and Recommendation.*
- ***2.2*** **Experimentation and Knowledge Discovery -** *Hypothesis Formulation. Survey of Print and Electronic Literature. Experimental Inquiry. Hypothesis Test, and Defense.*
- ***2.3*** **System Thinking -** *Thinking Holistically. Emergence and Interactions in Systems. Prioritization and Focus. Trade-offs, Judgement and Balance in Resolution.*
- ***2.4*** **Personal Skills and Attitudes -**
  Initiative and Willingness to Take Risks. Perseverance and Flexibility. Creative Thinking. Critical Thinking. Awareness of One's Personal Knowledge, Skills and Attitudes. Curiosity and Lifelong Learning. Time and Resource Management.
- **2.5 Professional Skills and Attitudes**
  Professional Ethics, Integrity, Responsibility and Accountability. Professional Behavior. (A professional bearing, Professional courtesy, International customs and norms of interpersonal contact). Proactively Planning for One's Career. Staying Current on World of Engineer.

3 INTERPERSONAL SKILLS. TEAMWORK AND COMMUNICATION

- **3.1 Teamwork**
  Forming Effective Teams. Team Operation. Team Growth and Evolution. Leadership. Technical Teaming.
- **3.2 Communication**
  Communications Strategy. Communications Structure. Written Communication Electronic/Multimedia Communication. Graphical Communication. Oral Presentation and Inter-Personal Communications.
- **3.3 Communication in Foreign Languages**
  English. Languages of Regional Industrialized Nations. Other Languages.

4 CONCEIVING, DESIGNING, IMPLEMENTING AND OPERATING SYSTEMS IN THE ENTERPRISE AND SOCIETAL CONTEXT

- **4.1 External and Societal Context**
  Roles and Responsibility of Engineers. The Impact of Engineering on Society Society's Regulation of Engineering. The Historical and Cultural Context. Contemporary Issues and Values. Developing a Global Perspective.
- **4.2 Enterprise and Business Context**
  Appreciating Different Enterprise Cultures. Enterprise Strategy, Goals, and Planning. Technical Entrepreneurship. Working Successfully in Organizations.
- **4.3 Conceiving and Engineering Systems**
  Setting System Goals and Requirements. Defining Function, Concept and Architecture. Modeling of System and Ensuring Goals Can Be Met. Development Project Management.

4.4 Designing
The Design Process. The Design Process Phasing and Approaches. Utilization of Knowledge in Design. Disciplinary Design. Multidisciplinary Design. Multi-Objective Design (DFX)

4.5 Implementing
Designing the Implementation Process. Hardware Manufacturing Process. Software Implementing Process. Hardware Software Integration. Test, Verification, Validation, and Certification. Implementation Management

4.6 Operating
Designing and Optimizing Operations. Training and Operations. Supporting the System Lifecycle. System Improvement and Evolution. Disposal and Life-End Issues. Operations Management.

THE CDIO STANDARDS

Standard 1 -- CDIO as Context
Adoption of the principle that product and system lifecycle development and deployment -- Conceiving, Designing, Implementing and Operating -- are the context for engineering education.

Standard 2 -- CDIO Syllabus Outcomes
Specific, detailed learning outcomes for personal, interpersonal, and product and system building skills, consistent with program goals and validated by program stakeholders.

Standard 3 -- Integrated Curriculum
A curriculum designed with mutually supporting disciplinary subjects, with an explicit plan to integrate personal, interpersonal, and product and system building skills.

Standard 4 -- Introduction to Engineering
An introductory course that provides the framework for engineering practice in product and system building, and introduces essential personal and interpersonal skills.

Standard 5 -- Design-Build Experiences
A curriculum that includes two or more design-build experiences, including one at a basic level and one at an advanced level.

Standard 6 -- CDIO Workspaces
Workspaces and laboratories that support and encourage hands-on learning of product and system building, disciplinary knowledge, and social learning.

Standard 7 -- Integrated Learning Experiences
Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal, interpersonal, and product and system building skills.

Standard 8 -- Active Learning
Teaching and learning based on active experiential learning methods.

Standard 9 -- Enhancement of Faculty CDIO Skills
Actions that enhance faculty competence in personal, interpersonal, and product and system building skills.

Standard 10 -- Enhancement of Faculty Teaching Skills
Actions that enhance faculty competence in providing integrated learning experiences, in using active experiential learning methods, and in assessing student learning.

Standard 11 -- CDIO Skills Assessment
Assessment of student learning in personal, interpersonal, and product and system building skills, as well as in disciplinary knowledge.

Standard 12 -- CDIO Program Evaluation
A system that evaluates programs against these twelve standards, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement.

APPENDIX B: YEAR-BY-YEAR LISTING OF COURSES

Year	**Chalmers, Sweden** Mechanical Engineering	**Queen's University, Canada** Mechanical & Materials Engineering	**Queen's University, UK** Mechanical & Manufacturing Engineering
1	• Introduction to Mechanical Engineering • Introductory Mathematics • Calculus 1 & 2 • Linear Algebra • Thermodynamics • Mechanics and Solid Mechanics 1 & 2 • Programming	• Practical Engineering Modules • Calculus I & II • Linear Algebra • Mechanics • Electricity & Magnetism • Chemistry & Materials • Chemistry & the Environment • The Earth's Physical Environment • Basic Engineering Graphics • Personal Computers in Engineering • Computer Programming for Engineers • Professional Engineering Skills	• Mathematics 1 • Further Mathematics 1 • Materials 1 • Thermodynamics 1 • Fluids 1 • Solids & Structures 1 • Engineering Dynamics 1 • Manufacturing Technology • Electrical Engineering • Engineering Design 1 • Computing & Professional Skills
2	• Material Science and Engineering A & B • Mechanics and Solid Mechanics 3 • Mechatronics • Manufacturing Technology • Integrated Design and Manufacturing • Engineering Economics • Integrated Production & Organization	• Statics & Solid Mechanics • Introductory Electric Circuits & Machines • Ordinary Differential Equations • Applications of Numerical Methods • Design Techniques • Manufacturing Methods • Instrumentation & Measurement • Kinematics & Dynamics • Thermodynamics 1 • Fluid Mechanics 1 • Materials Science & Engineering • Technical Communications	• Mathematics & Computing • Thermodynamics & Fluid Mechanics • Strength of Materials 2 • Engineering Dynamics 2 • Manufacturing Engineering • Electronics • Engineering Design 2 • Professional Studies 2
3	• Mathematical Statistics • Automatic Control • Environmental & Energy Systems • Fluid Mechanics • Major Project • Electives	• Solid Mechanics 2 • Machine Design • Dynamics & Vibration • Thermodynamics II • Fluid Mechanics II • Heat Transfer • Automatic Controls • Engineering Lab. I & II • Electronics • Engineering Data Analysis • Technical Electives • Complementary Studies	• Heat Transfer & Combustion • Strength of Materials 3 • Engineering Dynamics 3 • Production Management • Quality Systems 3 • Manufacturing Automation & Robotics • Engineering Design 3 • Professional Studies 3 • Project 3 (Individual)
4	Electives including: • Industrial Production and Organization courses • Project	• Design Project • Project Management & Economics • Technical Electives • Complementary Studies	• Professional Studies 4 • Innovation & Entrepreneurship • Project 4 (Team-based) • Electives

Year	**Linköping, Sweden** Applied Physics & Electrical Engineering	**MIT, USA** Aeronautics & Astronautics
1	• Engineering Project • Introductory Mathematics • Calculus • Vector Calculus • Linear Algebra • Numerical Methods I • Electronics • Digital Circuits	• Introduction to Aero & Astro • Calculus 1 & 2 • Physics • Chemistry • Humanities, Arts and Social Sciences
2	• Complex Analysis • Optimization • Probability & Statistics • Numerical Methods II • Mechanics • Wave Physics • Electromagnetic Field Theory • Programming • Computer Hardware & Architecture	• Differential Equations • Biology • Thermodynamics • Fluid Dynamics • Unified Engineering including: Statics Materials & Structures Propulsion Signals & Circuits Systems Software Engineering • Thermal Energy • Humanities, Arts and Social Sciences
3	• Fourier Analysis • Thermodynamics • Modern Physics • Signals & Systems • Control • Programming • Project Course in Electronics	• Probability & Statistics • Automatic Control • Dynamics • At least 2 *Professional Area Subjects* from: ➢ Fluid Mechanics ➢ Materials & Structures ➢ Propulsion ➢ Dynamics ➢ Computational Tools ➢ Estimation & Control ➢ Humans & Automation ➢ Computer Systems ➢ Communication Systems • Restricted Electives in Science & Technology • Humanities, Arts and Social Sciences
4	• Man, Technology & Society • Economics • Advanced Project Course • Electives	• At least 2 *Professional Area Subjects* • Capstone Project • Experimental Projects 1 & 2 • Restricted Electives in Science & Technology • Humanities, Arts and Social Sciences