THE CDIO APPROACH TO THE DEVELOPMENT OF STUDENT SKILLS AND ATTRIBUTES

Perry Armstrong
School of Mechanical & Aerospace Engineering
Queen's University Belfast

Robert Niewoehner
Aerospace Engineering
United States Naval Academy

Abstract
The CDIO approach includes a methodology for embedding the development of student skills and attributes in an engineering program. The methodology starts with the CDIO Syllabus which features a comprehensive list of skills and attributes. After progressing through a series of steps, an explicit plan is produced which indicates how the required skills and attributes should be developed within the curriculum. Implementing the methodology poses a number of challenges and these are discussed. It is also noted that other initiatives to improve graduate skills, dating back 10 to 15 years, have not resulted in any discernable improvement. The literature is then consulted and this leads to a number of proposals for enhancing the CDIO methodology. The outcome is a methodology that is more demanding to implement and further work is needed to provide support for the additional tasks that have been proposed. However it is argued that the enhanced methodology is more likely to ensure that students will graduate with the skills and attributes they require to become professional engineers.

Keywords: Engineering Education, CDIO, Student Skills

1. The Current CDIO Methodology

1.1 *Introduction*

Of the twelve "Standards" that characterize a CDIO engineering program eight include an explicit or implicit reference to student skills and attributes. (The word "attribute" is used in this paper to refer to student traits, characteristics and attitudes that would not normally be regarded as "skills".) Together the eight Standards that concern student skills and attributes outline a process whereby:

- Intended learning outcomes are defined for student skills and attributes (Standard 2).
- An explicit plan is devised to integrate the required skills and attributes into the curriculum (Standard 3).
- Courses designed to impart disciplinary knowledge are also tasked with developing student skills and attributes (Standard 7).

- Essential skills and attributes are introduced in the first year (Standard 4).
- Assessment processes are in place for student skills and attributes as well as disciplinary knowledge (Standard 11).
- Workspaces are provided that support and encourage the hands-on learning of student skills (Standard 6).
- Opportunities are made available for faculty to enhance their competence in the skills they are expected to teach (Standard 9) and their ability to teach them (Standard 10).

This paper will focus on the first two bullet points above i.e. the definition of appropriate learning outcomes for student skills and attributes and the development of an explicit plan for integrating skills and attributes into the curriculum. The current CDIO methodology, as it relates to these two tasks, is described in detail in the book "Rethinking Engineering Education: The CDIO Approach" [1]. However the following sections will provide an overview.

1.2 ***The CDIO Syllabus***

The process of defining learning outcomes for an engineering program begins with the CDIO Syllabus. This is a list of topics, skills and attributes that the collaborators in the CDIO Initiative believe should be addressed when learning outcomes are considered for the program. The list has a rationale which is based on the observation that engineering as a profession is responsible for the conception, design, implementation and operation of new and improved products, processes and systems (CDIO Standard 1). It follows that engineering students should acquire competence in the knowledge, skills and attributes associated with these activities, as they relate to the products, processes and/or systems identified with their discipline. The knowledge they will require includes the discipline-specific technical knowledge that is normally taught within an engineering program (which will be referred to as "disciplinary knowledge"). However they will also require a range of, mainly generic, competencies that are needed to take responsibility for the conception, design, implementation and operation of products, processes and systems (which will be referred to as "product, process and system building skills"). In addition it is obvious that professional engineers do not base their decisions on purely technical criteria. The commercial environment in which the majority work means that the "enterprise and business context" must be taken into account. Factors and issues beyond the enterprise also impinge on engineers' decision making and hence knowledge of the "external and societal context" is also a requirement. Furthermore it is self-evident that they must possess a wide range of "personal and professional skills and attributes". Finally since the contemporary engineer invariably works with other people, competence in "interpersonal skills" is mandatory. With these requirements in mind, it can be concluded that the knowledge, skills and attributes needed by a graduate engineer can be grouped into the following categories:

1. Technical knowledge and Reasoning.
2. Personal and Professional Skills and Attributes.
3. Interpersonal Skills.
4. Product Process and System Building Skills (taking the External and Societal Context and the Enterprise and Business Context into account).

Figure 1 summarizes the rationale behind the categories listed above.

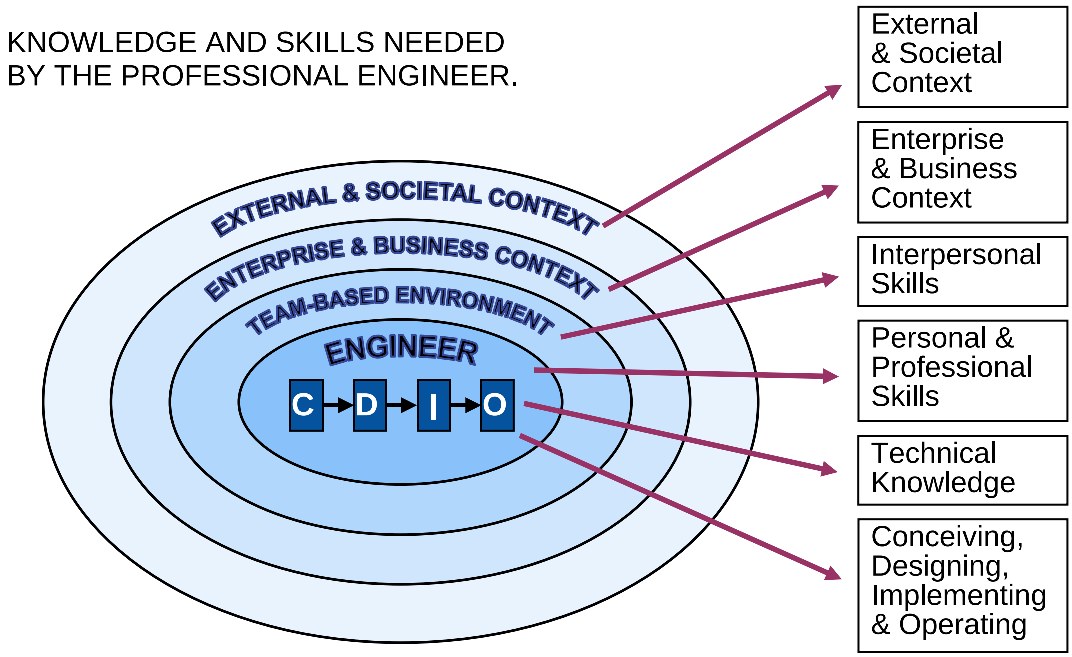

Figure 1 The Rationale for the Main Headings of the CDIO Syllabus

The CDIO Syllabus was created by adopting the above categories as its main headings and adding three more levels of detail. The addition of the first two levels of detail produced the so called X.X and X.X.X versions shown in Tables 1 and 2.

Table 1 The CDIO Syllabus (X.X Level)

1. Technical Knowledge
2. Personal and Professional Skills
2.1 Engineering Reasoning and Problem Solving
2.2 Experimenting and Knowledge Discovery
2.3 Systems 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 a Foreign Language
4. Product, Process and System Building 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 The CDIO Syllabus (X.X.X Level)

1 TECHNICAL KNOWLEDGE AND REASONING

2 PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES

2.1 ENGINEERING REASONING AND PROBLEM SOLVING

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

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 SYSTEMS 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
2.4.7 Time and Resource Management

2.5 PROFESSIONAL SKILLS AND ATTITUDES

2.5.1 Professional Ethics, Integrity, Responsibility and Accountability
2.5.2 Professional Behaviour
2.5.3 Proactively Planning for One's Career
2.5.4 Staying Current on World of Engineer

3 INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION

3.1 TEAMWORK

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 COMMUNICATION

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 COMMUNICATION IN FOREIGN LANGUAGES

4 CONCEIVING, DESIGNING, IMPLEMENTING, AND OPERATING PRODUCTS, PROCESSES & SYSTEMS

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
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

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

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

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

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

At the fourth level of detail (the X.X.X.X. version) the Syllabus occupies twelve pages of an appendix in the CDIO book [1]. As far as possible the sections of the Syllabus dealing with personal, professional, interpersonal and product, process and system building skills (Sections 2, 3 and 4) are intended to be applicable to all engineering disciplines. Section 1 is not expanded in detail, as the content will be specific to the engineering discipline concerned.

Comparisons have been drawn between the CDIO Syllabus, the ABET EC2000 criteria and the UK-SPEC accreditation criteria [1; pp 57-59]. The ABET criteria consist of the eleven intended learning outcomes listed in Table 3. The UK-SPEC criteria consist of 71 learning outcomes, grouped under the main headings listed in Table 4. It should be borne in mind, however, that the CDIO Syllabus is a list of topics, skills and attributes, rather than a list of learning outcomes.

Table 3 The ABET Learning Outcomes (Accreditation Criteria)

(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 multidisciplinary teams
(e) an ability to identify, formulate, and solve engineering problems
(f) an understanding of professional and ethical responsibility
(g) an ability to communicate effectively
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, 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.

Table 4 Main Headings of the UK-SPEC Learning Outcomes (Accreditation Criteria)

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

It is obvious that the CDIO Syllabus contains substantially more detail than the ABET criteria. Omissions from the ABET criteria are also evident, including explicit references to “systems thinking”, “the enterprise and business environment” and the need to address “implementation” and “operation” as well as “design”. Similarly “implementation” and “operation” are neglected in UK-SPEC. In addition the latter features limited coverage of professional skills and the personal and interpersonal skills cited are a generic set that applies to all university graduates, and not specifically to those studying for an engineering degree. On the other hand, it can be argued that the CDIO Syllabus lists all of the topics, skills or attributes referred to in the ABET and UK-SPEC criteria. Hence it is likely that a set of program learning outcomes based on the CDIO Syllabus will comply with both the ABET and UK-SPEC accreditation criteria.

An important aspect of the CDIO Syllabus is that it changes the context of engineering education. The Syllabus provides a reminder that engineering is a creative profession which is responsible for providing the new and improved products, processes and systems that customers, clients and society in general need or demand. It follows that engineering students must be provided with the necessary product, process and system building skills, if they are to function effectively as professional engineers. Logical additions to this requirement lead to the coherent syllabus that underpins the CDIO approach. In contrast, and primarily for historical reasons, the approach to engineering education that has been adopted over recent decades reflects a perceived need to produce graduates with a detailed knowledge of engineering science. The fact that professional engineers have to be familiar with non-engineering subjects, or need to be competent in a variety of skills, has only been acknowledged by occasionally “bolting on” additional courses that run in parallel with the engineering science curriculum. This has resulted in engineering programs that are piecemeal, lack coherence in educational terms and fail to fully prepare students for their roles as professional engineers. The CDIO approach takes a holistic view and first assembles all of the requirements for engineering education in a comprehensive and well-structured syllabus. Thereafter the challenge is to plan and deliver an integrated curriculum that will serve to meet these requirements, without sacrificing the need to produce graduates who are scientifically and mathematically competent.

1.3 ***Customizing the CDIO Syllabus***

While every effort was made to make Sections 2, 3 and 4 of the CDIO Syllabus applicable to all engineering programs, it was inevitable that some customization would be required, particularly at the lower levels. The customized version will reflect the needs and terminology of the specific engineering discipline involved, the views of faculty and the local and national context within which the university operates. However, experience has shown that the CDIO Syllabus provides an invaluable check list when the topics, skills and attributes at the lower levels are discussed.

1.4 ***Developing Program Learning Outcomes***

Ultimately it will be necessary to generate intended learning outcomes for a program i.e. statements indicating what students will be expected to know, understand and/or be able to demonstrate when they graduate. As a preparatory step it is important to establish what levels of proficiency graduates should have in the topics, skills and attributes listed in the customized version of the CDIO Syllabus. Opinions on this question should clearly be sought from all stakeholders, including employers, faculty and students, but most importantly from alumni, who will be aware of both the levels of competence they achieved at university and the levels of competence they have needed as graduates. The views of stakeholders may be captured in various ways, but document-based or on-line questionnaires provide quantitative input.

Details of stakeholder surveys are included in the CDIO book [1; pp 65-73]. To date the practice has been to seek stakeholder views on Sections 2, 3 and 4 of the Syllabus i.e. the personal, professional, interpersonal and product, process and system building skills expected of graduate engineers. (In the case of Section 1 it is assumed that the content of the program is well-established and that appropriate learning outcomes have already been defined.) In most cases the survey has been restricted to entries at the X.X level of the Syllabus (Table 1), but some universities have asked respondents to rate the X.X.X level entries (Table 2). The rating scale employed may involve descriptions of different levels of proficiency or simply ask how important a skill or attribute is for a graduate engineer, on the basis that the more important skills or attributes require a higher level of proficiency. When surveying alumni it is worth considering the inclusion of additional questions relating to the curriculum.

The results of surveys carried out at an early stage in the CDIO Initiative demonstrated two main points. One, perhaps surprising, finding was that different categories of stakeholder held similar views when asked about a specific degree program. The second main point was that different degree programs could produce relatively unique results. While not totally unexpected this underlines the fact that it is important that stakeholder opinion is sought for each individual degree program. As an illustration, Figure 2 compares the results obtained for programs at MIT and Queen's University Belfast (QUB).

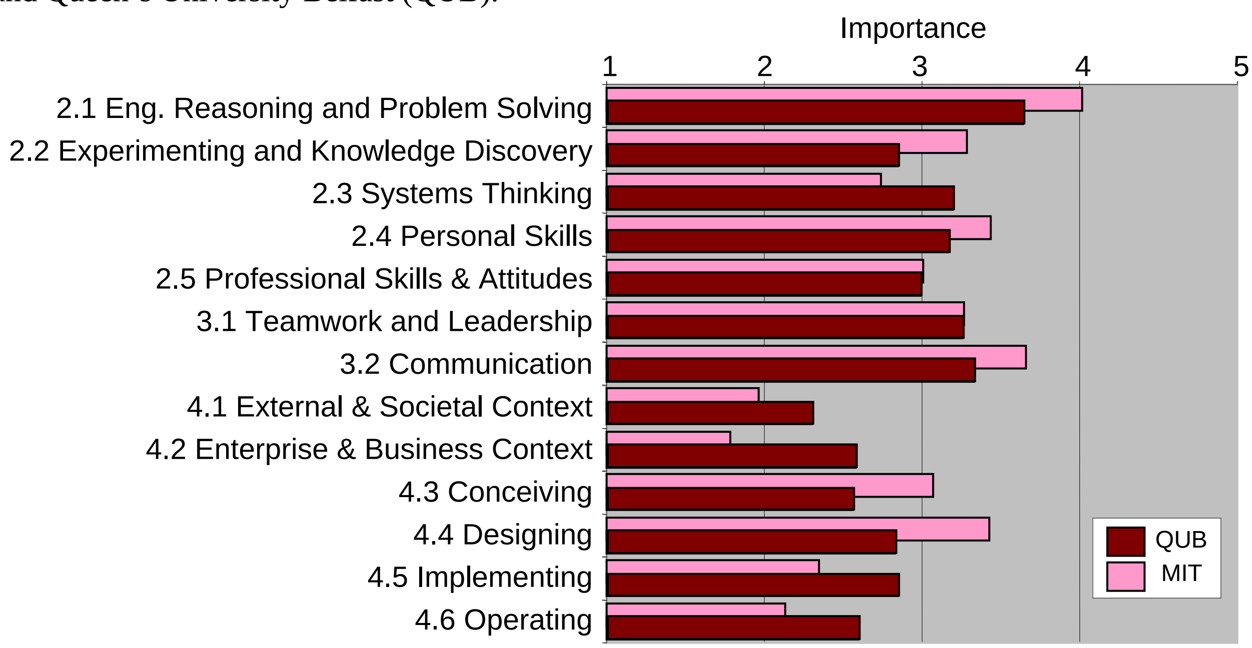

Figure 2 Views of MIT and QUB Alumni

It is apparent from Figure 2 that, compared to MIT alumni, QUB alumni attach more importance to knowledge of the business context and familiarity with manufacturing techniques (implementing). On the other hand "conceiving" and "designing" rate more highly with the MIT graduates. This should clearly be reflected in the intended learning outcomes for the programs concerned.

The conversion of a topic, skill or attribute in Sections 2 to 4 of a customized CDIO Syllabus to an intended learning outcome is primarily a matter of composing a statement containing a verb (and possibly an adverb) that describes how a graduate would demonstrate the required level of proficiency. Here it is useful to employ a taxonomy such as Bloom's taxonomy that defines different levels of cognitive ability, each of which can be associated with a particular collection of verbs. If each level of proficiency in a stakeholder survey is mapped to a level of cognitive ability, then an appropriate verb can be chosen which represents the required proficiency. This process is illustrated in the CDIO book [1; p74].

It has been noted that the ABET and UK-SPEC accreditation criteria cover a subset of the topics, skills and attributes listed in the CDIO Syllabus, but unlike the CDIO Syllabus the accreditation criteria are presented in the form of learning outcomes. In effect this means that the accreditation criteria already incorporate an assumed level of proficiency. Since gaining accreditation is important, it is obviously advisable to ensure that the proposed wording of the program learning outcomes indicates that the expected level of proficiency is at least commensurate with that implied by the corresponding accreditation criterion.

The process described above for creating a final set of program learning outcomes is outlined in Figure 3.

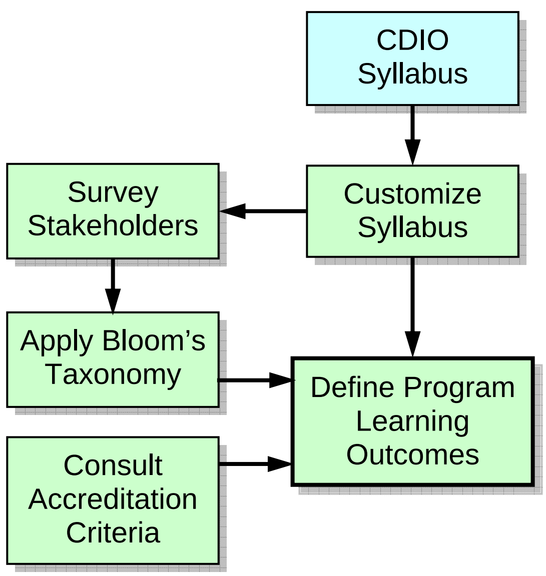

Figure 3 The CDIO Methodology: Developing Program Learning Outcomes

1.5 ***<u>Developing Course Learning Outcomes</u>***

Since learning outcomes are delivered in individual courses or modules, it will be necessary to assign or map program learning outcomes to particular courses. In the case of an existing degree program, it is likely that each course will already have a set of learning outcomes. For the most part the existing learning outcomes will be associated with the disciplinary knowledge included in Section 1 of the CDIO Syllabus. When it comes to Sections 2 to 4 of the Syllabus, it is likely that appropriate learning experiences will already be present in existing courses, but this may not be reflected in the course learning outcomes. However it is important that all existing learning experiences that develop skills and attributes are identified. Hence an audit is advisable to establish where and how student skills and attributes are currently being addressed in the program. The practice within the CDIO Initiative has been to conduct such an audit by benchmarking coverage of skills and attributes in the existing program against the X.X headings in the CDIO Syllabus. Some indication of the contribution made by individual courses is obtained by recording whether a particular skill is "introduced" (I), "taught" (T) or "utilized" (U). The result is a matrix of the type shown in Figure 4 which serves to provide an overview of the current coverage of student skills and attributes.

CDIO SYLLABUS	COURSES (2 YEAR DEGREE)											
	SEM 1			SEM 2			SEM 3			SEM 4		
	A	B	C	D	E	F	G	H	I	J	K	L
Section 2.1		I				T			U			
Section 2.2			U				U					
Section 2.3												
Section 2.4					I			U				T
Section 2.5												
Section 3.1												
Section 3.2	I				T			U		U		
Section 3.3		U		U			U					
Section 4.1												
etc.			T				T				I	

Figure 4 Benchmarking Current Coverage of Skills against Sections 2 to 4 of the CDIO Syllabus

The benchmarking exercise normally reveals the absence of planning in the development of student skills. Some skills in the CDIO Syllabus may never be developed, some may be utilized but never taught and some may be introduced or taught on a number of occasions by different faculty. Historically the curriculum has been designed to teach disciplinary knowledge in a manner where topics build upon each other in a logical sequence. In contrast the development of student skills and attributes is not normally planned at all, and skills are acquired almost incidentally.

CDIO Standard 3 calls for an "explicit plan" to integrate personal, professional, interpersonal and product, process and system building skills. The plan should specify "development paths" for each skill or skill set that will employ a logical sequence of learning experiences. The development path may include some of the learning experiences identified during the benchmarking exercise. The reference to integration in Standard 3 implies that the development of skills and attributes should be assigned to disciplinary courses. Standard 7 takes this further by advocating "integrated learning experiences" where skills are acquired at the same time as disciplinary knowledge. One argument for this is that it will result in the "dual use of time", and hence it will not be necessary to displace other content from the curriculum in order to accommodate the teaching of skills. Additional arguments are that students need to develop skills within an engineering context and, if they are taught by engineering faculty, they are more likely to accept the validity of learning a skill. However, a repercussion is that engineering faculty need to acquire competence in teaching skills. Standards 9 and 10 recognize this implication by requiring support for faculty to enhance their own skills and also develop their ability to deliver integrated learning experiences. As part of the necessary support, resources are being assembled within the CDIO Initiative, called Instructor Resource Materials (IRMs), which include materials, suggestions and assessment tools for teaching specific skills.

Figure 5 summarizes the process of integrating the development of skills.

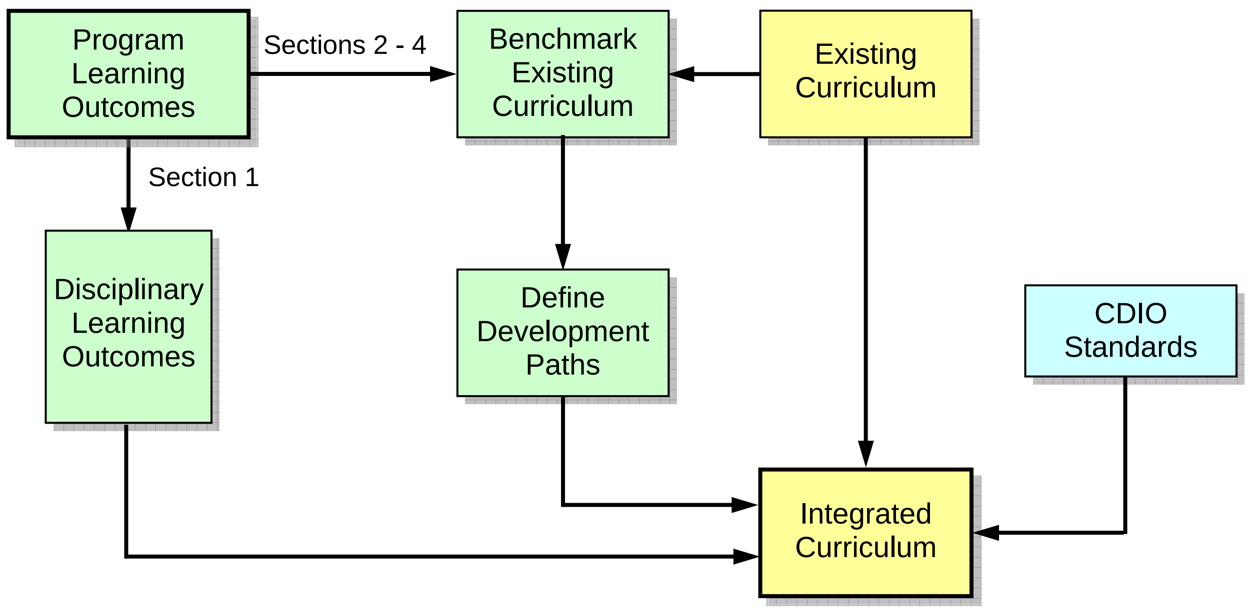

Figure 5 The CDIO Methodology: Developing an Integrated Curriculum

In Figure 5, the learning outcomes for disciplinary knowledge are dealt with separately. The assumption is that it will only be necessary to review the current outcomes against those associated with Section 1 of the customized CDIO Syllabus. The final integrated curriculum will also reflect changes made as a result of implementing the CDIO Standards concerned with curriculum and course design, such as Standard 4 which calls for the inclusion of an introductory course. The development paths will be “woven” into the curriculum and will consist of logical sequences of integrated learning experiences delivered in the disciplinary courses taught by engineering faculty.

2. Implementing the CDIO Methodology

2.1 *The Challenges*

Implementing the CDIO methodology outlined above is a relatively daunting task. The initial steps should pose no major difficulties, up to the point where program learning outcomes are produced. The CDIO Syllabus needs to be reviewed and customized. Stakeholder opinions have to be obtained and appropriate verbs need to be selected to convert Syllabus entries into learning outcomes, which are at least as demanding as any accreditation criteria that apply to the program. Since program learning outcomes are normally broadly based, these initial steps need only involve the upper levels of the CDIO Syllabus. However, significant challenges arise when it comes to producing an "explicit plan" for creating an integrated curriculum. The current CDIO methodology lacks detailed guidance as to how the plan should be produced and there are a number of issues that the methodology does not address.

The principle that the development of student skills and attributes should be integrated into the curriculum is undoubtedly sound. Students learn more effectively and are more motivated to learn when the context is their discipline. There is overwhelming support in the literature for this principle [2, 3, 4, 5, 6, 7, 8]. There is also significant support in the literature for the argument that acquiring skills involves "slow learning" which is complex and takes a significant amount of time [9, 10]. Various initiatives for integrating specific skills across the curriculum have been reported in the literature, concerning for example teamwork and problem solving [11], information literacy [6] and communication skills [12]. The consensus is that staged tuition has to be provided from introductory to advanced concepts, with frequent opportunities for students to practise the skills involved. As Culver et. al. [13] note, competence "must grow progressively and intentionally over the four years of the program". They add that "once the framework is developed, it is possible to determine in which course(s) and at what time each objective is to be addressed in the program". This implies that the "explicit plan" referred to in Standard 3 has to be a program-wide plan which includes a detailed "framework" (strategy) for each program outcome <u>before</u> a course or courses are selected to deliver the outcome.

It is also important to recognize that the preferred approach of the CDIO collaborators, whereby an individual academic takes responsibility for a skill within his or her disciplinary course, may not always be feasible. The research culture in many universities means that some academics are reluctant to teach a disciplinary subject that is not directly related to their research area, let alone a skill that they will have to learn how to teach. Hence there is a need to take a broader look at the full range of opportunities for developing student skills and attributes.

The wisdom of considering all possible opportunities for developing student skills and attributes is perhaps self-evident. However this becomes essential when the comprehensive nature of the CDIO Syllabus is taken into account. While the program learning outcomes may be associated with its upper levels, the fine details of the Syllabus refer to a wide variety of skills and attributes. If, in addition, it is recognized that the effective development of a particular skill will involve a multi-stage process, it is obvious that a substantial number of learning opportunities will have to be identified, and a systematic approach to producing the "explicit plan" will be needed in order to deal with the complexity of the task. In fact there is a distinct possibility that there will be insufficient learning opportunities in the existing curriculum. Hence the planning process may well have to consider how additional opportunities can be created in order to develop all of the required skills and attributes.

It is noted that implementing a program-wide plan to integrate skills and attributes requires a top-down approach to course content that runs counter to current practice in most universities. The majority of engineering programs have a modular structure with a core of courses assigned to engineering science subjects. Decisions on course content are normally delegated to the subject expert responsible for the course, and hence the curriculum tends to evolve from the bottom up. The need to accommodate a new subject is generally dealt with by introducing a new course. Hence, when it was decided a few decades ago that engineering students in the UK should be familiar with business and management subjects, new courses were introduced under the banner title of "Professional Studies". Many engineering programs still include these courses in each year of the program (mainly for accreditation purposes). Lectures are often given by external experts who have no engineering experience, and inevitably students have difficulty relating the subject matter to their chosen discipline. In principle the remedy is obvious, but there is no published evidence of successful implementations of top-down plans to embed Professional Studies topics within the teaching of disciplinary subjects. The difficulties undoubtedly stem from a lack of clarity as to who should take on the task of developing the plan, a shortage of expertise in the topics concerned and the fact that many faculty do not see it as their responsibility to teach a non-engineering topic in their disciplinary course.

In summary the main challenges involved in implementing the CDIO methodology are:

- The difficulties involved in developing a complex program-wide plan that includes a detailed strategy for delivering each program outcome relating to student skills and attributes.
- The need to consider all possible learning opportunities for developing skills and attributes, and the need to create additional learning opportunities if this is necessary.
- The requirement for a top-down approach which may raise a number of difficulties including a lack of available expertise and the likelihood of resistance from faculty.

2.2 *Other Initiatives to Develop Student Skills*

The development of student skills has of course been a major issue in higher education for ten years or more. At times engineering education has had to contend with different requirements emanating from various government, professional and university bodies. This has been less of a problem in the USA where the ABET EC2000 criteria have provided a single focus for engineering educators. The EC2000 criteria represented a radical departure from previous criteria, both in terms of their brevity and the prominence they gave to developing student skills. The response of engineering educators in the USA has been to produce an epic volume of literature on the subject. In contrast, engineering education in the UK has had to respond to a series of national initiatives concerning the development of student skills across all academic disciplines. Impetus was provided by the Dearing Inquiry which in 1997 recommended that "graduate skill proficiency" should be incorporated in all university curricula [14]. The terminology used in the UK has evolved from "key skills", through "transferable skills" to the current preference for "employability skills". In the light of the number of UK government initiatives it is perhaps fortunate that the UK-SPEC criteria do not include learning outcomes for personal and interpersonal skills, but instead refer to a set of national requirements for all university graduates. On the other hand this means that there is limited guidance on the specific skills that should be developed within engineering education in the UK. As a result the debate on the subject pales in comparison with that taking place among engineering educators in the USA. The situation in Australia differs again from the USA and the UK. Here the term "graduate attributes" has gained currency, and developments relating to student skills are widely reported in the literature. As a result of government concerns each university has developed generic requirements which are then customized at the level of individual disciplines [15]. At the same time engineering education in Australia has a comprehensive set of accreditation criteria to meet, which include a variety of criteria relating to student skills and attributes [16].

No significant evidence has been published to demonstrate the success of the British or Australian initiatives referred to above. In fact Drummond [4] describes the overall picture in the UK as “not very encouraging” and notes that “there is little evidence of effective practice on any large scale.” Walker and Radcliffe [17] quote from a recent report by the Business Council of Australia which claims that engineering graduates still have deficiencies with respect to crucial job skills such as “problem-solving, communication and entrepreneurship”. Some of the responsibility for the lack of progress has been attributed to academics. Drummond [4] claims bluntly that “many academics are cynical of the arguments being used to promote the significance of PTS (Personal Transferable Skills)”. Barrie [18] describes a recent research study of Australian academics’ views on how students acquire generic attributes. He reports that some do not regard the teaching of such attributes as the university’s responsibility. Others believe that generic attributes should be taught in separate courses unconnected with the disciplinary curriculum. Tellingly he notes that “the single most prevalent conception expressed by the academics interviewed was of generic attributes as relatively unimportant additive outcomes, taught as a supplement to the more important discipline content”. The negative perceptions of academics are cited by the author as a significant barrier to progress.

In the USA the main problem reported in the literature has been the lack of guidance on how to meet the skill-based outcomes listed in the ABET criteria. Felder and Brent [19] note that most discussion in the literature has focused on how to assess the ABET outcomes and “relatively little has concerned how to equip students with the skills and attitudes specified in those outcomes”. The authors go on to point out that equipping students with the necessary skills is much harder than determining whether or not they have the skills. Following an extensive review of published papers and reports, Moore et. al. [20] reinforce the point that the literature on meeting the ABET criteria “lacks depth and breadth in providing detailed guidance that engineering faculty can use”.

It is evident that the literature does contain some examples of good and ostensibly successful practice, when it comes to developing specific skills. Some elements of good practice have also been reported that make a contribution to the challenge of integrating skills into the curriculum. What appears to be lacking is an overarching methodology that can be used to plan and deliver an integrated curriculum that successfully develops the full range of required skills and attributes. Undoubtedly the current CDIO methodology goes some way towards meeting this requirement. However to qualify as a solution it will be necessary to detail and possibly extend the CDIO methodology in order to overcome the challenges discussed in Section 2.1. In the following sections these challenges are revisited and possible additions to the methodology are proposed, which draw upon some of the good practice reported in the literature.

3. Detailing the Program Learning Outcomes

Program learning outcomes will normally be aligned with the upper levels of the CDIO Syllabus. However if development paths for specific skills are to be devised, the program outcomes will have to be expanded in some detail in order to produce learning outcomes that can be assigned to individual learning experiences along each development path. Clearly the lower levels of the CDIO Syllabus provide an important guide to the topics or skills that should be referred to in the detailed learning outcomes. As was the case when defining the program outcomes, Bloom's taxonomy can be used to suggest appropriate verbs for the detailed learning outcomes. In an important contribution, Besterfield-Sacre et. al. [21] suggest that program learning outcomes should first be divided into "outcome elements". (Despite the terminology these are topics rather than learning outcomes.) Bloom's taxonomy is then applied to each outcome element in order to produce detailed learning outcomes for each level in the taxonomy. The authors refer to the detailed learning outcomes as "measurable attributes". This is said to be a pre-emptive step in order to facilitate assessment, although arguably all learning outcomes should be measurable. Table 5 illustrates the process.

Table 5. Expanding a Program Learning Outcome to produce a set of "Measurable Attributes"

Program Learning Outcome	Levels of Learning: Bloom's Taxonomy						
	Knowledge	**Comprehension**	**Application**	**Analysis**	**Synthesis**	**Evaluation**	**Valuation**
Outcome Element 1	• • • •	• •	• • •	• • •	• •	• • • •	• •
Outcome Element 2	• •	•	• • •	• • • •	• • •	• • • •	• • •
Outcome Element 3	• • •	• • •	• • • •	• •	• • •	•	• • •
Outcome Element 4	• •	• • •	• • • •	• •	• • • •	• • •	• • •

As the table indicates the authors define measurable attributes for each of the six levels of Bloom's cognitive domain, with the addition of a seventh level which comes from the affective domain (valuation). Action verbs are chosen from those associated with each of the levels in the domain. The authors demonstrate their approach by generating measurable attributes for one of the ABET learning outcomes, but tables of measurable attributes for all of the ABET outcomes can be found at the website www.engrng.pitt.edu/~ec2000. In the paper, discussion of the purpose of listing the attributes is limited to a statement that educators can pick and choose attributes for use in their own courses. The authors make no mention of planning the development of skills or devising development paths.

In a later paper Mourtos [22] describes how a similar approach to that proposed by Besterfield-Sacre et. al. [21] was used to generate attributes for the ABET learning outcome relating the lifelong learning. However the author extends the process to include all five levels of Bloom's

affective domain. In addition he describes how the resulting attributes were grouped and assigned to a sequence of six courses in an Aerospace Engineering program.
Of particular interest is a recent paper by Froyd et. al. [23]. The authors, who are from Texas A & M, focus on “systems thinking” and note its absence from the ABET criteria. Instead they turn to the CDIO Syllabus, and comment that the Syllabus is the “best supported, most comprehensive, and thoroughly detailed set of expectations that the authors found in the literature”. As a further departure, they choose to generate learning outcomes by adopting a revised version of Bloom’s taxonomy [24]. The latter uses verbs rather than nouns to identify the levels in the cognitive domain, and the previous fifth and sixth levels are interchanged. The revised taxonomy is applied to the four X.X.X. topics under the Systems Thinking heading in the CDIO Syllabus and the results are shown diagrammatically in Table 6.

Table 6. Measurable Attributes for “Systems Thinking”

2.3 Systems Thinking	Levels of Learning: Revised Bloom’s Taxonomy					
	Remember	Understand	Apply	Analyze	Evaluate	Create
2.3.1 Thinking Holistically	• • • •	•	• • •	• • • •	• •	• • • •
2.3.2 Emergence and Interactions in Systems	• •	• •	• • •	•	• • •	•
2.3.3 Prioritization and Focus	• • •	•	• • • •		• • •	•
2.3.4 Trade-offs, Judgment and Balance in Resolution	• •	• • • •	• • • •	• •	• • • •	• • •

As an example of the learning outcomes listed in the cells of Table 6, the following are included in the “Analyze” cell for “Thinking Holistically”:

- Given the context of a design challenge, create a concept map that depicts the system parts, its boundary, its environment, and the relationships among them.
- Create a chart that illustrates the effect of at least two decisions on the parts of the system and the interactions among the parts.
- Describe how interactions between the system and its environment might influence decisions made in the process of addressing the design challenge.
- Create a chart that shows how the system, boundary, environment, and their interactions change if the decision maker shifts focus among natural science, social science, humanities or combinations of the three.

It is noted that Froyd et. al. do not start with a program outcome, but a CDIO Syllabus topic. They then use the next level down to produce the “outcome elements”, to use the terminology proposed by Besterfield-Sacre et. al. [21]. Their intention is not to detail a program learning outcome, but to generate learning outcomes directly for a particular skill or topic. The authors do not use the term “measurable attribute”, but note that the outcomes produced should relate to “observable student performance”. However the term “measurable attributes” will be adopted in this paper, in order to denote the detailed outcomes produced by the process described above.

The matrix of 24 cells shown in Table 6 contains 83 learning outcomes for “systems thinking”, which perhaps underlines the challenge involved in fully addressing skills within the curriculum. The revised version of Bloom’s taxonomy used by the authors does not revisit the affective domain. It is argued that cognitive learning outcomes normally have an affective component, and separating this out is unnecessary [24]. However the revised taxonomy does add a second dimension to the cognitive domain. This identifies the type of knowledge involved and four categories are listed; factual knowledge, conceptual knowledge, procedural knowledge and meta-cognitive knowledge. Although little would be gained by further dividing the measurable attributes into these four categories, they do serve as reminders of the type of knowledge to be considered when defining measurable attributes. It is useful, for example, to be reminded that the cognitive domain includes procedural knowledge, as this is important in the acquisition of various skills. In addition the meta-cognition category provides a “home” for some of the learning outcomes that may previously have been assigned to the affective domain.

As an addition to the CDIO methodology, it is suggested that the approach discussed above be adopted. This means that a further step needs to be included in Figure 5, as shown in Figure 6.

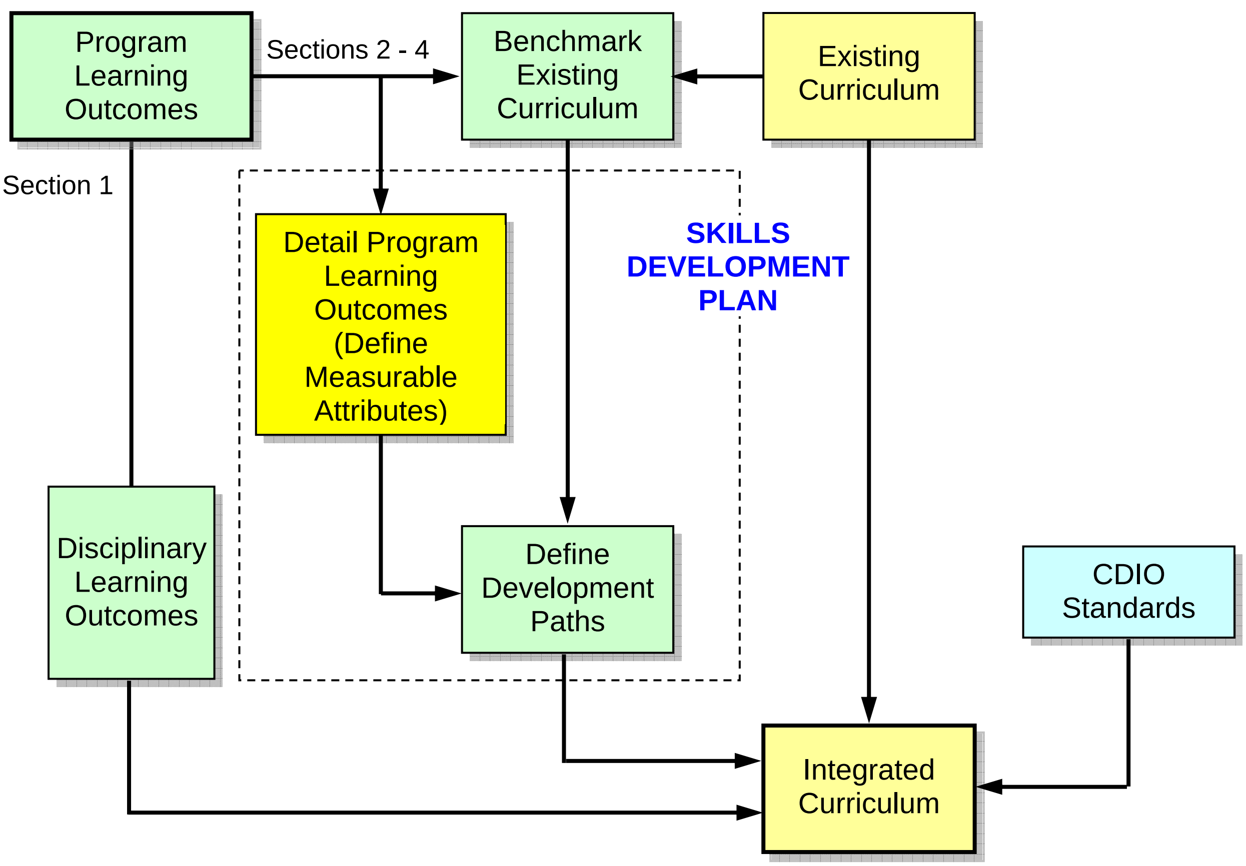

Figure 6 Adding “Detail Program Outcomes” to the CDIO Methodology

In Figure 6 the term "Skills Development Plan" has been introduced to describe the "explicit plan" for developing skills referred to in CDIO Standard 3. As indicated in the figure, the benchmarking exercise included in the current CDIO methodology provides input to the Skills Development Plan. The additional step shown in Figure 6 is to expand each program learning outcome in detail as the first step in producing the plan. The intention is that the method described by Besterfield-Sacre et. al. [21] should be employed. However, it is suggested that the revised version of Bloom's taxonomy be adopted, since it has a number of advantages.

There is an obvious risk of measurable attribute proliferation. Hence it is proposed that the program outcomes should be limited, at least in the first instance, to one for each of the fourteen X.X topics in Sections 2 to 4 of the CDIO Syllabus. This is compatible with the existing methodology, where input from the stakeholder surveys is usually applied to the X.X topics when program outcomes are defined. The end result will be fourteen tables similar to Table 6 (except that a program outcome will appear in the top left corner rather than the name of the topic involved). On the basis of the results presented by Froyd et. al. [23], this may still generate many hundreds of measurable attributes. However this is the logic of the outcomes-based approach, and the tables produced will provide ample information for assigning learning outcomes (measurable attributes) to individual learning experiences on the development paths. In addition it is clearly beneficial that the taxonomy orders the measurable attributes according to the level of cognitive ability involved. This will assist the task of defining learning experiences, since the sequence will generally deliver learning outcomes (measurable attributes) from the "Remember" column to begin with and then move across the table to the column for "Create".

4. Reviewing and Expanding Learning Opportunities

4.1 *Introduction*

The benchmarking of existing courses will naturally reveal learning opportunities to develop skills that can be employed again. However, considering the likely number of measurable attributes to be addressed, it is clearly advisable to review all possible learning opportunities and to identify additional opportunities if required. The following is a list of areas where opportunities to develop student skills and attributes may be available:

1. Lecture-based Courses
2. Project-based Courses
3. Laboratory Classes
4. Work Placements
5. Study Abroad Programs
6. Extra-curricular Activities

Each of the above areas is considered in turn.

4.2 *Lecture-based Courses*

It will be assumed that the lecture-based courses in the curriculum are disciplinary courses, or courses on subjects that are closely aligned with the discipline. The preference within the current CDIO methodology is that these courses will provide the vehicle for developing student skills and attributes, through integrated learning experiences (Standard 7).

It is generally accepted that learning a skill requires tuition or instruction. Culver et. al. [13] present a table which shows that there is knowledge to be acquired in connection with all eleven ABET outcomes. Studies of individual skills have demonstrated the benefits of instruction, including one by Ogot and Okudan [25], which showed that students who were taught TRIZ produced more creative ideas than a control group who had no knowledge of this systematic concept generation technique. However it is also accepted that students only fully develop a skill through active learning which enables them to practise the skill thoroughly. In addition it is important that their active learning is supported by formative feedback.

Although a lecture may impart some of the knowledge required to develop a skill, assignments provide the main opportunity in lecture-based courses for the active learning needed to develop skills. In fact there is significant potential in assignments for skill development. As Oxnam [8] notes "many course assignments can be easily adjusted to incorporate one or more skills". The author's focus is on information literacy, and he cites literature searches, practice at writing various types of document and oral presentations as candidates for practising skills in assignments. If student teams are formed to carry out an assignment, opportunities will be created to exercise a wider range of skills, including communication, leadership and obviously teamwork skills. Of course more substantial assignments can also be considered where students apply the disciplinary knowledge they have acquired in a design or design-implement exercise. This may be called a project rather than an assignment, but the clear benefit is that students also have the opportunity to practise their product, process or system building skills.

The potential of assignments for developing skills and attributes is seldom fully realized. Assignments are often included in a course for the purposes of summative assessment, and are generally focused on student understanding of the lecture content. A different outlook is therefore needed where, in addition, assignments are seen as important opportunities for developing student skills and attributes. In part this is a question of designing the assignment to exploit the opportunity, but the academic involved must have sufficient expertise and be willing to provide formative feedback on the skills involved in the assignment.

4.3 ***Project-based Courses***

Courses where project work predominates are considered in this section. The project work may involve students completing a single project or a series of projects. A project-based course may also include lectures that are delivered in parallel with the project work, or that alternate with periods of project work. The material covered in the lectures is not normally assessed directly through a written examination, but through its contribution to the project work.

Virtually all engineering programs include a project-based course in the final year, which is known as a capstone course in the USA. The implication is that the course completes a student's education by providing an opportunity to demonstrate what has been learnt in the preceding years. This may suggest that the purpose of the capstone course is summative. However a survey of capstone courses in the USA reported by Howe and Wilbarger [26] showed that around 80% of capstone courses include lectures on a variety of subjects. In fact the survey, which was carried out in 2005, indicated that the lecture content in capstone courses has increased significantly compared to a similar survey completed in 1994. The topics covered are primarily concerned with student skills, with oral communication proving to be the most popular topic, followed by ethics, project planning and teamwork. In the majority of cases lectures are delivered in parallel with the project work and, compared to 1994, there has been a significant increase in capstone projects where students work in teams.

Clearly project-based courses provide the main opportunity in a program to develop students' skills and attributes. Pierrakos et. al. [27] report a survey of the learning outcomes addressed in a capstone design course, which was based on the opinions of both students and faculty. The authors identify 20 personal and professional outcomes and 30 technical outcomes for the course, almost all of which concern student skills and attributes. Apart from teamwork and communication skills the list includes self-assessment, taking initiative, developing self-confidence and perseverance, improving organizational skills and recognizing the need for lifelong learning.

From a CDIO point of view it is important that students have the opportunity to develop not only their design skills, but also the skills involved in the conception, implementation and operational stages of the product, process or system lifecycle. Put another way, if possible D projects should be extended to D-I projects or C-D-I projects, and ideally to C-D-I-O projects. Adopting this policy will ensure that project-based courses achieve their full potential for promoting product, process or system building skills. Andersson et. al. [28] describe how one CDIO collaborator uses the Formula Student (Formula SAE) competition to provide a C-D-I-O project which addresses all of the topics in the conceiving, designing, implementing and operating sections of the CDIO Syllabus.

The Formula Student competition provides an excellent opportunity for students to practise a wide variety of skills, and also to learn some new skills. Undoubtedly project supervisors (and fellow students) regularly provide formative feedback that supports the learning process. However, a Formula student project does not necessarily include lectures that run in parallel with the project work. In their absence the full potential for developing student skills and attributes may not be realized. Armstrong et. al. [29] describe another example of a project-based course introduced by a CDIO collaborator. The course also features a C-D-I-O project, but a series of lectures and seminars runs in parallel with the project to provide instruction and guidance as the students encounter the need for new skills. In effect a project-based learning (PBL) model has been adopted, where input is provided on the knowledge and skills required as the project proceeds. Although the CDIO approach does not recommend PBL as a model for an entire degree program, it can be argued that implementing PBL in individual project-based courses is the best policy for ensuring the effective development of skills and attributes.

CDIO Standard 5 requires "a curriculum that includes two or more design-implement experiences, including one at a basic level and one at an advanced level". In fact some would argue that "design-implement experiences" should feature in every year of a program. This could be guaranteed if the curriculum included a project-based course in each year (which could be the introductory course referred to in CDIO Standard 4 in the first year, and the capstone course in the final year). The continuity provided would allow students to progressively enhance the full range of their skills from year to year. It is perhaps worth drawing a comparison at this point between engineering and medicine. In 1993 the General Medical Council (GMC) in the

UK recommended the introduction of a new curriculum model for medical schools. More recently Robley et. al. [30, 31] have reviewed the implementation of the model, which requires project-based courses in every year of a medical degree, to run alongside the core curriculum. A key purpose of the project-based courses is to develop "a range of generic skills that are considered essential to professional medicine in the twenty-first century". The fact that the integrity of the core curriculum is preserved mirrors the CDIO approach, and it could be argued that the GMC's planned sequence of project-based courses across all years should also be a requirement of the CDIO approach. Robley et. al. [30, 31] present results that demonstrate the success of the GMC model in a particular UK university.

4.4 ***Laboratory Classes***

Laboratory classes are usually included in the curriculum to supplement and support the core engineering science courses. Unfortunately as Truax [32] observes students are often presented with "a set of tried and tested cookbook experiments". Feisel and Rosa [33] place much of the blame for this situation on "the lack of coherent learning objectives for laboratories". As a response Most and Deisenroth [34] propose a set of 13 learning outcomes that should be considered when designing a laboratory class. Virtually all of the learning outcomes concern student skills and attributes. This suggests that laboratory classes should be viewed as important learning opportunities for student skills and attributes.

The skills most obviously associated with laboratory work appear in Section 2.2 of the CDIO Syllabus, which deals with Experimentation and Knowledge Discovery. However students will not have the opportunity to practise many of the skills listed in Section 2.2 if laboratory experiments simply follow a "cookbook" approach. Hence the enhancement of laboratory classes to include more open-ended experiments and provide students with choices will be necessary if they are to be regarded as learning opportunities for the skills in Section 2.2.

Traditionally there has been a tendency to "invent" laboratory experiments in order to fill all of the timetable slots in a laboratory program. A more sensible policy would be to critically evaluate the current laboratory experiments and, if necessary, replace those that are unsatisfactory with more productive learning experiences. Project work is an obvious alternative, and McDermott et. al. [35] describe how substituting project-related activities for conventional laboratory sessions enabled project work to be introduced into all years of an engineering program. In a similar vein, one of the CDIO collaborators has replaced a sequence of three laboratory classes with a team-based project to design, build and test a beam made from MDF [1; p111]. The project is competitive which means that it contributes to team building as well as reinforcing students' knowledge and understanding of beam theory.

In effect the traditional laboratory program can be regarded as a timetable construct where groups of students participate in a sequence of activities, with the sequence followed by each group offset by one week. All of the activities may involve laboratory experiments, but one or more of the activities may be assigned to a design-implement experience or any other learning experience that contributes to the program outcomes. In this sense laboratory classes provide flexibility and there is no reason why they should not be regarded as potential learning opportunities for various skills and attributes.

4.5 ***Work Placements***

What is referred to as a "work placement" in the UK becomes a "co-operative program" or an "internship" in the USA. In all cases the student gains experience of working in a real engineering environment. This is generally regarded as highly beneficial. A paper by Rowe and Mulroy [36] claims that the "evidence suggests that graduates with work experience have more employment opportunities than those without" and that "students returning from work experience outperform students who haven't been in the workplace in terms of performance in their final year". Hence the perception is that work experience promotes student development. However only a limited number of studies have been reported that define the specific benefits of work experience, or identify the learning outcomes addressed by a work placement.

One contribution to the debate is reported by Brumm et. al. [37], who describe a survey designed to assess the competencies developed by students through co-operative programs and internships. The 14 chosen competencies were mapped to the ABET learning outcomes to show that all eleven were covered. The results obtained show agreement between students and supervisors that the competencies that benefit most from work experience are integrity, cultural adaptability, professional impact, quality orientation and teamwork. Perhaps surprisingly communication was ranked in the bottom three competencies by both students and supervisors.

In another study Canale et. al. [38] surveyed student opinion across a variety of engineering programs in two universities. The students were asked to assess the percentage contribution to the eleven ABET outcomes from periods on placement in a co-operative program, compared to periods in the classroom. The results consistently cited the outcomes relating to teamwork, ethical and professional responsibility, knowledge of contemporary issues and communication as benefiting most from work experience.

It is likely that work experience contributes to a wide range of student skills and attributes. However, there is some evidence from the above studies to suggest that university-based and workplace learning opportunities may be complementary. The competencies that gained most from work experience in the first study, apart from teamwork, are not readily developed in a university setting. The same can be said for ethical and professional responsibility and knowledge of contemporary issues, which were among the ABET outcomes that gained most in the second study. The advantages of work placements are obviously worth bearing in mind when assessing learning opportunities for developing skills and attributes, and it is tempting to advocate that a work placement should be an integral part of every engineering program.

4.6 ***Study Abroad***

Studying or working in another country for a period during an engineering degree program has become reasonably common in Europe, but is much less popular in the USA [39]. Only 2.9% of the American students who studied abroad in 1999-2000 were engineering students [40]. There are a number of obvious reasons why international experience is becoming more important, and one is its potential role in developing student skills and attributes. However there is little quantitative evidence for the benefits of studying abroad, and advocates have to rely on anecdotal evidence. Hence Machotka and Spodek [40] claim that it has been said that "engineering students who have participated in a study abroad program are better problem-solvers, have strong communication and cross-cultural communication skills, and are able to work well in groups of diverse populations and understand diverse perspectives". The authors add that they "are more adaptable to new environments and have a greater understanding of contemporary issues, as well as engineering solutions in a global and societal context".

In a recent paper Mello et. al. [41] describe a scheme at an American university which involves students undertaking a two month project outside the USA. The authors present data based on an evaluation of reports submitted by returning students, where each student was rated against five of the ABET learning outcomes. The results show a clear distinction between students who completed projects on-campus in the host country and those who undertook projects off-campus. In the case of the on-campus projects the average rating was acceptable for only one of the ABET outcomes. However those who carried out projects off-campus were awarded higher scores for all five ABET outcomes, and were rated as acceptable for three; namely teamwork, ability to engage in life-long learning and understanding of the impact of engineering on society. These results suggest that study abroad may need some planning if its potential benefits are to be realized. It may be that the claims of Machotka and Spodek are not universal, and that students who are simply "sent" abroad do not automatically benefit in the manner the authors suggest.

4.7 ***Extra-curricular Activities***

It is obvious that universities cannot "reach directly into students' extra-curricular activities" [9]. However, Barrie [18] notes that universities need to "harness the learning potential of (students') engagement with other facets of university life outside of their formal classes". In a similar vein Kuh [42] discusses "out-of-class experiences" and argues that "universities need to view them as part of, rather than separate from or competing with, traditional curricula and the classroom".

A recent study by Tchibozo [43] tries to define and differentiate between the main types of extra-curricular activity, with a view to establishing a link between the type of activity a student engages in and his or her employment prospects. The categories he identifies, which are presented in descending order of employment prospects, are:

1. Leaders and Citizens
2. Sportspersons
3. Activists and Clients

An implication of the author's findings may be that students should be encouraged to seek positions of responsibility and become involved in "citizenship" activities in order to develop their employability skills.

An alternative stance may be that universities should simply encourage students to become aware of the potential role that extra-curricular activities have in developing their skills and attributes. This is in fact one of the objectives of Personal Development Planning (PDP), which all universities in the UK have been required to introduce. (A companion paper presented at this conference [44] discusses PDP and its potential links with CDIO.) PDP involves each student maintaining a "progress file", in hardcopy or electronic form, which he or she uses to record evidence of the development of skills that would be useful in employment or in gaining employment. It is also suggested that students should identify and record ways of gaining skills that they currently lack. Students are encouraged to consider all spheres of their lives, and hence extra-curricular activities are just as valid as classroom experiences. (It could be added that students are also encouraged to view work experience and study abroad as significant opportunities to develop their skills.)

It is hoped that PDP will encourage students to take more responsibility for their personal development, and improve their ability to learn independently. In terms of the implications for skills, there are undoubtedly extra-curricular activities that promote the development of required skills and attributes. Some PDP implementations involve students discussing their progress files with personal tutors. If this is the case, then feedback from tutors may be used to suggest activities that are more likely to help students develop their skills. Such interventions may result in more students becoming members of the "leaders and citizens" group.

4.8 *Extending the CDIO Methodology*

It has been argued that reviewing and expanding potential learning opportunities for skills and attributes is another task that needs to be undertaken when producing a Skills Development Plan, and this is shown as a further addition to the CDIO methodology in Figure 7.

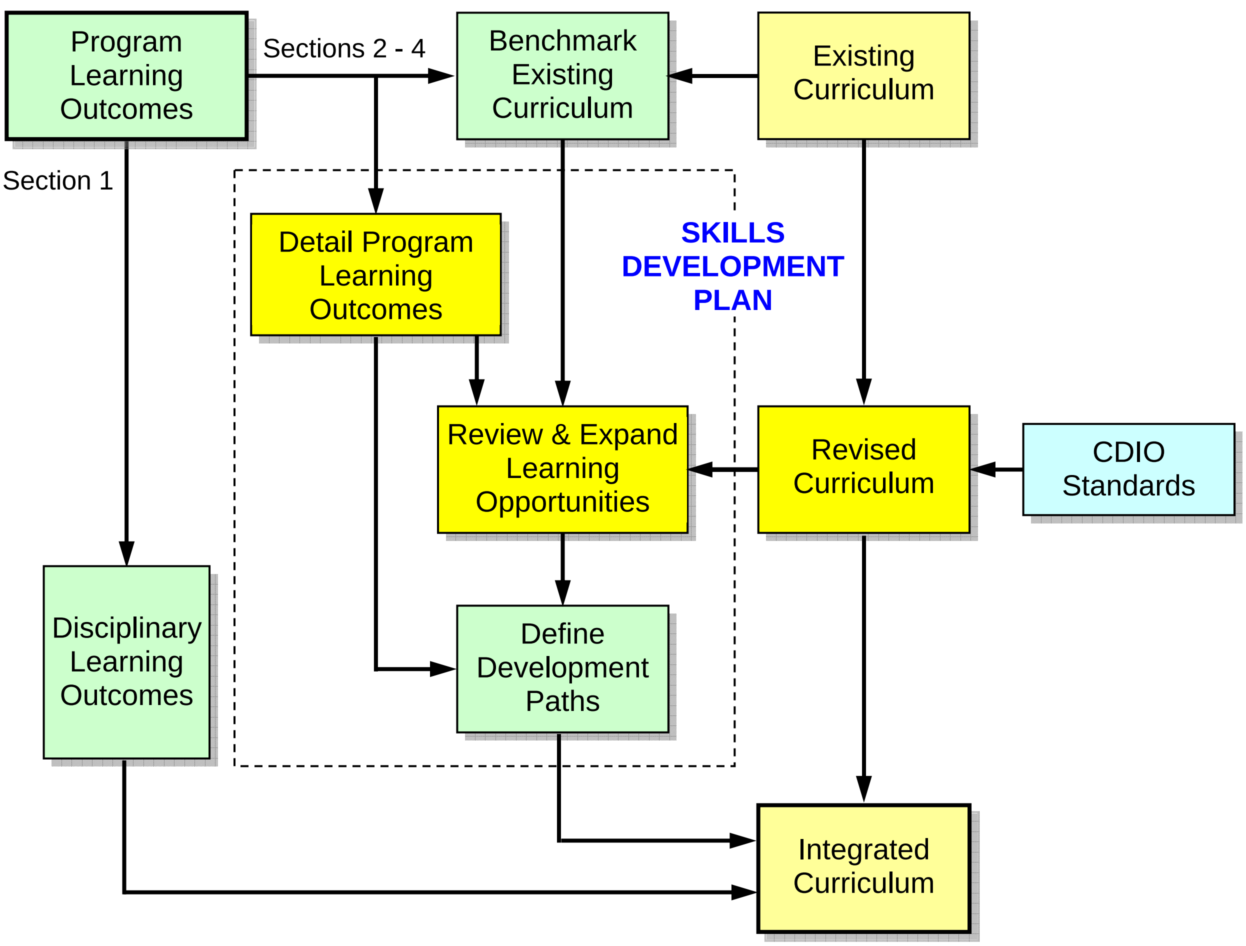

Figure 7 Adding "Review & Expand Learning Opportunities" to the CDIO Methodology

Figure 7 also differs from Figure 6 because the CDIO Standards relating to course and curriculum design are now implemented before the development paths are defined. The purpose is simply to ensure that any additional learning opportunities created by applying the Standards are taken into account. As examples, a new introductory course may be added to the curriculum or a new assignment may be introduced in order to increase active learning in a disciplinary course.

4.9 ***Summary***

This section has reviewed the main areas where learning opportunities may be available to develop student skills and attributes. The following suggestions have been made as to how additional opportunities may be created if, as seems likely, there are insufficient opportunities to cater for the multi-stage development of all required skills and attributes:

- Include a project-based course in every year of the program.
- Extend projects to cover more lifecycle stages e.g. extend design projects to design-implement projects or design-implement projects to conceive-design-implement-operate projects.
- Adopt a PBL approach in project based courses.
- Expand assignments and projects in lecture-based courses to increase the scope for developing skills and attributes.
- Ensure that formative feedback is provided in all instances where students are developing skills.
- Enhance laboratory classes to maximize the potential for learning skills.
- Replace unproductive laboratory classes with small-scale design-implement exercises.
- Introduce or expand work placement schemes.
- Introduce or expand study abroad opportunities.
- Encourage students to recognize that they can develop and improve their skills through appropriate extra-curricular activities.

5. Producing the Skills Development Plan

Sections 3 and 4 outlined some of the tasks that would be involved in producing a Skills Development Plan. More detail is added in this section and additional tasks are identified and discussed. As previously indicated, the first step is to produce a table of measurable attributes for each program learning outcome. As noted, limiting the program outcomes to one per X.X heading in the CDIO Syllabus will mean that the total number of tables will be a manageable 14. Each table may be similar in form to Table 7. (Note that Table 7 has been rotated through 90° compared to Tables 5 and 6. This change is made so that progression from the lower to the higher levels of cognitive ability is downwards, and therefore consistent with the direction of time in the figures which follow Table 7.)

The measurable attribute tables are next used to create “development paths” consisting of sequences of “learning experiences”, each of which will address a set of measurable attributes (drawn from the appropriate table by working downwards). The number of development paths may exceed 14, if separate development paths are needed for individual outcome elements or combinations of outcome elements.

Table 7. Measurable Outcomes for a Program Learning Outcome

Program Learning Outcome	Outcome Element 1	Outcome Element 2	Outcome Element 3
Remember	• •	•	•
Understand	• •	•	•
Apply	• •	•	•
Analyze	•	• •	•
Evaluate	•	•	• •
Create	•	• •	•

As discussed in Section 4 it will generally be necessary to expand the number of available learning opportunities before forming the development paths. Figure 7 illustrates how an expanded set of learning opportunities could be presented, based on the suggestions made in Section 4.

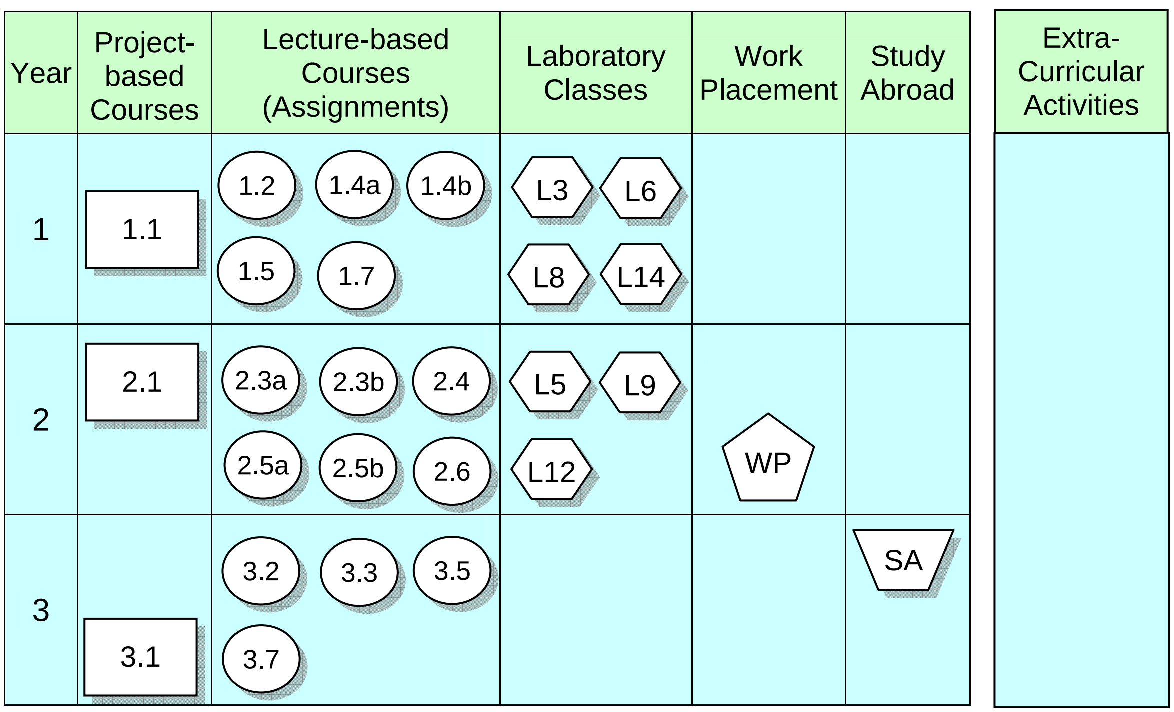

Figure 7 Available Learning Opportunities

Figure 7 covers the curriculum areas discussed in Section 4 and the symbols are coded in order to indicate their location in the curriculum. A column for “Extra-curricular Activities” is included, on the basis that it would be appropriate for the Skills Development Plan to consider the introduction of something similar to the Personal Development Planning system that has become mandatory in the UK.

Forming a development path for a program outcome or outcome element becomes a matter of selecting a sequence of learning opportunities from those shown in Figure 7. The results of the selection process could be presented in a table similar to that shown in Figure 8.

Development Path for Program Learning Outcome or Outcome Element			
Measurable Attributes (Learning Outcomes)	Learning Opportunity	Learning Experience	Means of Assessment
• • • •	1.1		
• • •	1.4b		
• •	L8		
• • • • •	2.1		
• •	2.5b		
• • • • •	WP		
•	3.2		

Figure 8 Formation of a Development Path

The first column in Figure 8 lists the measurable attributes that will be addressed by each of the chosen learning opportunities. (Ultimately the measurable attributes will form the basis for additional learning outcomes that will be assigned to the learning opportunity's "host" course.) The third column is included in order to record details of the learning experience that will develop the required measurable attributes. The last column indicates how the students are going to be assessed, which in effect means how the measurable attributes are going to be evaluated. The final Skills Development Plan will consist of a collection of tables similar to the one shown in Figure 8.

6. <u>The Need for Guidance, Assistance and Support</u>

It would be desirable if some guidance were available to assist with the challenging task of selecting learning opportunities and designing learning experiences to develop a particular set of measurable attributes. However, as noted in Section 2.2, there is a lack of published work on the best way to equip students with the skills and attributes referred to in program learning outcomes. Having discussed this problem, Bjorklund and Fortenberry [45] report the results of an exhaustive literature survey to identify "instructional principles and practices" that contribute to the attainment of the eleven ABET outcomes (plus four outcomes that the authors believe should be added to the ABET list). The authors conclude that published evidence only exists for a limited number of principles and practices, which they list as:

- Encouraging student-faculty interaction.
- Developing reciprocity and cooperation among students.
- Providing prompt feedback.
- Using active learning techniques.
- Respecting diverse talents and ways of thinking.
- Building on correct pre-existing understandings; dispelling false preconceptions.

While these findings are of interest, they do not directly assist the task of selecting appropriate learning opportunities or designing suitable learning experiences.

Brumm et. al. [7] do consider the relative merits of different types of learning opportunity. Their results are presented in terms of the probability that a particular type of learning experience will develop various competencies (needed in the workplace). The probabilities are derived from a survey of the stakeholders in a number of engineering programs. The competencies do not correlate directly with the ABET outcomes, but do include lifelong learning, innovation, communication, teamwork, initiative and integrity. The results rate the learning opportunities available during work placement most highly, followed by the capstone design project and "extra-curricular activities related to the engineering profession". The "traditional" classroom setting receives the lowest rating for most of the specified competencies, and in the majority of cases the classroom is rated lower than "extra curricular activities that are not related to the engineering profession". The authors conclude that the results confirm the importance of experiential education. However there are again no useful indicators that would help with the choice of learning opportunities or the design of learning experiences to deliver required outcomes.

Shuman et. al. [46] present a review of how the skills in the ABET criteria are taught and assessed in American universities. The authors note that teamwork and communication skills are generally developed through project work, whereas design courses and case studies are commonly used to develop professional and ethical responsibilities. The authors also claim that study abroad programs improve students' understanding of the societal and global context and their knowledge of contemporary issues.

In their paper Shuman et. al. [46] suggest that the ABET skills can be divided into "process skills" and "awareness skills". The former are characterized by the fact that students develop the skill by learning an explicit process. The latter involve gaining a general understanding of requirements, influences, issues or constraints. There may be some benefit in pursuing the authors' suggestion, and grouping the skills and attributes in the CDIO Syllabus into the suggested categories. However it is evident that the CDIO Syllabus refers to a number of "personal traits", and these would need to form a third category. Examples of entries in the CDIO Syllabus that could be assigned to the proposed categories are listed in Table 9.

Table 9 Classifying Entries in the CDIO Syllabus

Process Skills	**Awareness Skills**
Engineering Reasoning & Problem Solving	Staying Current on World of Engineer
Experimentation & Knowledge Discovery	External & Societal Context
Systems Thinking	Enterprise & Business Context
Critical Thinking	
Creative Thinking	**Personal Traits**
Time & Resource Management	Self-confidence
Teamwork	Enthusiasm
Communication	Initiative
Career Planning	Perseverance
Designing	Adaptability
Implementing	Accepting of Criticism

The lists in Table 9 do not include all of the entries in the CDIO Syllabus, partly because the appropriate category for a number of entries will depend on the wording of the associated learning outcomes. However, classification may have merit as a precursor to the identification of development paths. In the case of the "process skills", development within the curriculum should be possible, with each development path consisting of a repeating sequence of learning experiences that involve tuition, practice (with formative feedback) and assessment. The development of "awareness skills" will usually benefit from some transfer of knowledge or information. However, the evidence suggests that a full appreciation will generally require learning experiences outside the university. Hence when planning development paths for awareness skills, learning opportunities should be considered that occur during work placements, periods of study abroad or relevant extra-curricular activities. Clearly these are areas of learning where faculty have little control but, if a PDP system has been introduced, tutors can at least discuss with their students how their time away from the university can be used to develop their "awareness skills".

The most challenging category of the three is "personal traits". In the literature these are often called "attitudes", and sometimes "abilities". Whichever term is used, they are not referred to in either the ABET or UK-SPEC accreditation criteria. However, Hoadley [47] notes that several studies have shown that "attitudes are important in the effective use of knowledge and skills when accomplishing engineering tasks". The author's context is the publication of prerequisites for professional practice by the American Society of Civil Engineers (ASCE) [48]. Unlike ABET, ASCE incorporates "attitudes" in its prerequisites, and suggests that the attitudes "that support the effective practice of civil engineering" can include "commitment, confidence, consideration of others, curiosity, fairness, high expectations, honesty, integrity, intuition, good judgment, optimism, persistence, positiveness, respect, health self esteem, sensitivity, thoughtfulness, thoroughness and tolerance".

Some would argue that personal traits are innate characteristics that cannot be modified. However, the Harvard psychologist David McClelland is adamant that there is "no solid evidence" that any human trait cannot be changed [49]. Walther and Radcliffe [12, 17, 50] also take this stance, but caution against the idea that all student attributes can be developed directly through “targeted instruction”. This notion they argue is too simplistic in the case of “person variables”. In fact the authors maintain that the complexity of human behaviour and the many influences on students mean that they can develop unintended or “accidental competencies” or, in some cases, “accidental incompetencies”.

Scott and Yates [51] support the contention of Walther and Radcliffe that the overall student experience can, in effect, produce emerging properties. They carried out a survey of “successful graduates” where respondents identified a variety of capabilities they had acquired that were not explicitly taught in their degree programs, but arose from their “total university experience”. The authors maintain that steps can be taken to develop the capabilities the respondents identified as important in professional practice. Their suggestions include highlighting the development of the most important attributes during work placements and placing greater emphasis on real-world problems. However, as with other authors, they provide little advice on the specific curriculum-based initiatives that are likely to result in students developing desirable traits. Instead they maintain that “we must look to the total university experience as a resource, not just to what happens in the traditional classroom”. They add that this includes “enhancing the social and support components of university provision” and facilitating “open co-operation between students”.

It would appear from the above discussion that, in seeking ways to influence student traits, more attention should be paid to the environment in which students study and learn. Based on common sense, the learning environment should be stimulating in order to encourage curiosity, and student achievements should be rewarded in order to help develop confidence. In addition, as Scott and Yates [51] suggest, relationships need to be supportive and co-operation between students should be facilitated. This in fact mirrors the results discussed earlier that were reported by Bjorklund and Furtenberry [45], where “encouraging student-faculty interaction” and “developing reciprocity and co-operation among students” were cited as important when it comes to achieving the ABET outcomes. Hence it could be argued that creating a positive learning environment has a significant role to play in promoting various student skills and attributes, including personal traits.

The term “learning community” has a relatively specific meaning in the USA [52], but the term can be used in a general sense to describe a situation where students taking a program (or a year of a program) work and socialize together and interact effectively with faculty. The task of creating a positive learning environment could then be interpreted as one of developing a vibrant “learning community”. This would involve providing the necessary physical space, facilities and resources to support such a community. It could also involve encouraging and facilitating extra-curricular activities that promote student development.

Of course, informal learning communities of engineering students have always existed. The contention here is that promoting the concept of a learning community should be viewed as a means of contributing to the delivery of program outcomes. In turn this implies that the Skills Development Plan should consider proposals for facilitating, resourcing and enhancing the learning community (or communities) associated with a program, as a means of promoting desirable personal traits and contributing to the development of skills and attributes in general.

The task of producing a Skills Development Plan clearly presents a daunting prospect. Inevitably a team of people will be involved and the team will have to be given the authority to modify the curriculum and discuss the creation of additional learning opportunities with the faculty who teach the program. Prince et. al. [11] describe the formation of a team to plan the progressive development of students' teamwork and problem solving skills across the curriculum. Since the plan was to cover five engineering programs, the team consisted of representatives from each program plus two "instructional technologists". The authors describe the process used to generate detailed learning outcomes, which made use of the measurable attributes produced by Besterfield-Sacre et. al. [21] for the ABET outcome on teamwork. Of interest is the comment by Prince et. al. [11] that "It was found that faculty teams are harder to form than student teams but are essential since individual faculty efforts are not capable of producing systemic change".

When it comes to designing the learning experience that will develop a particular set of measurable attributes, the current CDIO methodology regards this as the responsibility of the engineering academic who teaches the "host" course. An alternative is for the engineering academic to collaborate with an expert in the skill involved, in order to design, and possible help deliver, an appropriate learning experience. There are a variety of examples of collaboration for this purpose reported in the literature. Kedrowicz [12] describes how teachers from colleges of engineering and the humanities collaborated to embed the learning of communication skills in a series of engineering courses. Lengsfeld et. al. [53] report co-operation between departments of engineering and English to develop and deliver a course that covers engineering design and communication skills. Oxnam [8], Nerz and Bullard [54] and Welker et. al. [6] discuss different initiatives to integrate information literacy into engineering courses, which involved collaboration between engineering faculty and library staff.

The presence of library staff in universities means that expertise should be widely available to assist with the integration of information literacy skills. It is also of note that professional organizations associated with librarianship have produced detailed learning outcomes for information literacy, an example of which appears in Welker et. al. [6]. This suggests that collaboration with library staff may be advisable at an earlier stage in the formation of the Skills Development Plan, before any attempt is made to produce measurable attributes for information literacy. The same argument will apply in the case of other skills where expertise is available, since clearly it should be fully utilized.

7. Conclusions

The need to produce graduates with the skills and attributes required to become professional engineers lies at the heart of the CDIO Initiative. The CDIO collaborators have devised a methodology for generating program outcomes that specify the skills and attributes to be acquired. CDIO Standard 3 then calls for an "explicit plan" to integrate the required skills and attributes into the curriculum. However there is a need for more detailed guidance on how the "explicit plan" should be produced. In this paper the "explicit plan" is referred to as the "Skills Development Plan", and it has been proposed that additional steps be included in the CDIO methodology to facilitate the specification of development paths for the required skills and attributes. The first step involves expanding each program learning outcome, using the revised version of Bloom's taxonomy, in order to produce sets of measurable attributes requiring progressively higher levels of cognitive ability. The next step involves a detailed analysis of all available learning opportunities, which may lead to proposals for course or curriculum changes that would produce additional opportunities. The remaining steps are to select sequences of learning opportunities to form the development paths and to devise appropriate learning experiences. Additional issues that could be addressed by the Skills Development Plan include the possible introduction of a Personal Development Planning system and consideration of measures to promote the development of a learning community linked to the program. It has also been suggested that all possible assistance should be sought from others with expertise in developing the required skills. Even if significant assistance is available, it is recognized that there will be a substantial amount of work involved in producing the Skills Development Plan.

One of the remaining challenges is the lack of guidance relating to the selection of appropriate learning opportunities and the design of effective learning experiences. The CDIO collaborators may have a role to play in this regard. There will be a degree of commonality between the program learning outcomes adopted by all collaborators, and there are likely to be similarities between the lists of measurable attributes that the collaborators produce. It would therefore seem reasonable to suggest that a collaborative exercise should be undertaken to expand a typical set of program outcomes in order to produce typical sets of measurable attributes. This would, to an extent, mirror the exercise undertaken by Besterfield-Sacre et. al. [21] to generate measurable attributes for the ABET learning outcomes. Since engineering programs may differ significantly, there will be less commonality in the learning opportunities and experiences used by different collaborators to create development paths. However obvious benefits would accrue from sharing experience of forming development paths for particular skills and building up a knowledge base. Exploiting the collaborative nature of the CDIO Initiative in this way could make an important contribution to one of higher education's current dilemmas, apart from demonstrating that the CDIO collaborators had achieved success where others have failed.

References

[1] Crawley E.F., Malmqvist J., Ostlund S. and Brodeur D.R., "Rethinking Engineering Education: The CDIO Approach", Springer Science+Business Media, New York, 2007.
[2] Barrie S.C., Jain P. and Carew A., "Generic Graduate Attributes: A Research Based Framework for a Shared Vision", Staff and Educational Development International, Vol. 7(3), 2003, pp 191-199.
[3] Cranmer S., "Enhancing graduate employability: best intentions and mixed outcomes", Studies in Higher Education, Vol. 31(2), 2006, pp 169-184.
[4] Drummond I., Nixon I. and Wiltshire J., "Personal Transferable Skills in Higher Education: The Problems of implementing good Quality Assurance in Education", Vol. 6(1), 1998, pp 19-27.
[5] Drake M.J., Griffin P.M., Kirkman R. and Swann J.L., "Engineering Ethical Curricula: Assessment and Comparison of Two Approaches", Journal of Engineering Education, Vol. 94(2), 2005, pp 223-231.
[6] Welker A.L., Quintiliano B. and Green L., "Information Literacy: Skills for Life", Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition.
[7] Brumm T.J., Hanneman L.F. and Mickelson S.K., "Assessing and Developing Program Outcomes through Workplace Competencies", International Journal of Engineering Education, Vol. 22(1), 2006, pp 123-129.
[8] Oxnam M., "The Informed Engineer", Proceedings of the 33rd ASEE/IEEE Frontiers in Education Conference, Boulder, CO, November 5-8, 2003.
[9] Yorke M. and Knight P.T., "Embedding Employability into the Curriculum", Learning and Employability Series 1, The Higher Education Academy, York, 2006.
[10] The Higher Education Academy, "Pedagogy for Employability", Learning and Employability Series 1, The Higher Education Academy, York, 2006.

[11] Prince, M., Hanyak M., Hoyt R., Hyde D.C., Mastascusa E.J., Snyder W., Toole T.M., Higgins T., Shooter S., Wagner M., Vigeant M. and Aburdene M., “A Conceptual Framework for Progressively Developing Students' Team and Problem Solving Skills Across the Curriculum”, Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition.
[12] Kedrowicz, A., “Developing Communication Competence: A Comparison of the Intensive Capstone Experience and Developmental Integration”, Proceedings of the 2007 American Society for Engineering Education Annual Conference & Exposition.
[13] Culver R., McGrann R. and Lehmann G., “Preparing Students for ABET a – k”, Proceedings of the 35th ASEE/IEEE Frontiers in Education Conference, Indianapolis, IN, October 19-22, 2005.
[14] Cox S. and King D., “Skill sets: an approach to embed employability in course design”, Education + Training, Vol. 48(4), 2006, pp 262-274.
[15] Goldsworthy A., “Developing generic Skills: Examples of Best Practice”, B-HERT News, Issue 16, April 2003.
[16] Radcliffe D.F., “Innovation as a Meta-Attribute for Graduate Engineers”, International Journal of Engineering Education, Vol. 21(2), 2005, pp 194-199.
[17] Walther J. and Radcliffe D. F., “The competence dilemma in engineering education: Moving beyond simple graduate attribute mapping”, Australasian Journal of Engineering Education, Vol. 13(1), 2007, pp 41-51.
[18] Barrie S.C., “A conceptual framework for the teaching and learning of generic graduate attributes”, Studies in Higher Education, Vol. 32(4), 2007, pp 439-458.
[19] Felder R.M. and Brent R., “Designing and Teaching Courses to Satisfy the ABET Engineering Criteria”, Journal of Engineering Education, Vol. 92(1), 2003, pp 7-25.
[20] Moore, P.D. Cupp S.M. and Fortenberry N.L., “Linking Student Learning Outcomes to Instructional Practices - Phase II”, Proceedings of the 34th ASEE/IEEE Frontiers in Education Conference, Savannah, GA, October 20-23, 2004.
[21] Besterfield-Sacre M., Shuman L.J., Wolfe, H., Atman C.J., McGourty, J., Miller, R.L., Olds B. and Rogers G., “Defining the Outcomes: A Framework for EC 2000”, IEEE Trans on Engineering Education, Vol. 43(2), 2000, pp 100-110.
[22] Mourtos N.J., Defining, “Teaching and Assessing Lifelong Learning Skills”, Proceedings of the 33rd ASEE/IEEE Frontiers in Education Conference, Boulder, CO, November 5-8, 2003.
[23] Froyd J., Pchenitchnaia L., Fowler D. and Simpson N., “Systems Thinking and Integrative Learning Outcomes”, Proceedings of the 2007 American Society for Engineering Education Annual Conference & Exposition.
[24] Anderson L.W., Krathwohl D.R., Airasian P.W., Cruickshank K.A., Mayer R.E., Pintrich P.R., Raths, J. and Wittrock M.C. (Eds), “A Taxonomy for Learning, Teaching and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives”, Longman, New York, 2001.
[25] Ogot M. and Okudan G.E., “Integrating Systematic Creativity into First-Year Engineering Design Curriculum”, International Journal of Engineering Education, Vol. 22(1), 2006, pp 109-115.
[26] Howe S. and Wilbarger J., “2005 National Survey of Engineering Capstone Design Courses”, Proceedings of the 2006 American Society for Engineering Education Annual Conference & Exposition.
[27] Pierrakos O. and Tech V., “Assessing Learning Outcomes of Senior Mechanical Engineers in a Capstone Design Experience”, Proceedings of the 2007 American Society for Engineering Education Annual Conference & Exposition.
[28] Andersson S.C., Malmqvist J., Knutson Wedel M. and Brodeur D.R., “A Systematic Approach to the Design and Implementation of Design-Build-Test Project Courses”, International Conference on Engineering Design (ICED 05), Melbourne, August 15-18, 2005.
[29] Armstrong P., Kee R., Kenny, R. and Cunningham G., “The Development of a Capstone Project Course based on CDIO principles”, World Transactions on Engineering and Technology Education, Vol. 5(2), 2006, pp 299-302
[30] Robley W., Whittle S. and; Murdoch-Eaton D., “Mapping generic skills curricula: a recommended methodology, Journal of Higher and Further Education”, Vol. 29(3), 2005, pp 221-231.
[31] Robley W., Whittle S. and; Murdoch-Eaton D., “Mapping generic skills curricula: outcomes and discussion”, Journal of Higher and Further Education, Vol. 29(4), 2005, pp 321-330.
[32] Truax D.D., “Improving the Learning Process of Laboratory Instruction”, Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition.
[33] Feisel L.D. and Rosa A.J., “The Role of the Laboratory in Undergraduate Engineering Education”, Journal of Engineering Education, Vol. 94(1), 2005, pp 121-130.
[34] Most K.R. and Deisenroth M.P., “ABET and Engineering Laboratory Objectives: A Study at Virginia Tech”, Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition.

[35] McDermott K.J., Nafalski A. and Gol O., “Project-based Teaching in Engineering Programs”, Proceedings of the 37th ASEE/IEEE Frontiers in Education Conference, Milwaukee, WI, October 10-13, 2007.
[36] Rowe J.W.K. and Mulroy T.J., “A Qualitative Study of the Student Internship Experience”, Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition.
[37] Brumm T.J., Hanneman L.F. and Mickelson S.K., “The Data are in: Student Workplace Competencies in the Experiential Workplace”, Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition.
[38] Canale R., Cates C. and Duwart E., Co-op and ABET 2000: “The Added Learning Dimension!”, Proceedings of the 2000 American Society for Engineering Education Annual Conference & Exposition.
[39] Klahr S.C. and Ratti U., “Increasing Engineering Student Participation in Study Abroad: A Study of US and European Programs”, Journal of Studies in International Education, Vol. 4, 2000, pp79-102.
[40] Machotka M. and Spodek S., “Study Abroad: Preparing Engineering Students for Success in the Global Economy”, Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition.
[41] Mello N., DiBiasio D. and Vaz R., “Fulfilling ABET Outcomes by Sending Students Away”, Proceedings of the 2007 American Society for Engineering Education Annual Conference & Exposition.
[42] Kuh G.D., “The Other Curriculum: Out-of-Class Experiences Associated with Student Learning and Personal Development”, The Journal of Higher Education, Vol. 66(2), 1995, pp 123-155.
[43] Tchibozo G., “Extra-Curricular Activity and the Transition from Higher Education to Work”: A Survey of Graduates in the United Kingdom, Higher Education Quarterly, Vol. 16(1), 2007, pp 37-56.
[44] Armstrong P., Cunningham G., McCartan C., Hermon P. and Kenny R., “Supporting CDIO with Personal Development Planning”, Proceedings of the 4th International CDIO Conference, Hogeschool Gent, Gent, Belgium, June 16-19, 2008.
[45] Bjorklund S.A. and Fortenberry N.L., “Linking Student Learning Outcomes to Instructional Practices - Phase III”, Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition.
[46] Shuman L.J., Besterfield-Sacre, M and McGourty J., “The ABET "Professional Skills" - Can They Be Taught? Can They Be Assessed?” Journal of Engineering Education, Vol. 94(1), 2005, pp 41-55.
[47] Hoadley P, “The ASCE BOK and Attitudes Assessment”, Proceedings of the 2007 American Society for Engineering Education Annual Conference & Exposition.
[48] ASCE, “Civil Engineering Body of Knowledge for the 21st Century: Preparing the Civil Engineer for the Future”, American Society of Civil Engineers, Reston, Virginia, 2004.
[49] McClelland D.C., “Testing for Competence Rather than for Intelligence”, American Psychologist, Vol. 28, 1973, pp 1-14.
[50] Walther J. and Radcliffe D.F., “Accidental Competency Formation: An Investigation of Behavioral Learning in Engineering Education”, Proceedings of the 2007 American Society for Engineering Education Annual Conference & Exposition.
[51] Scott G. and Yates K.W., “Using Successful Graduates to Improve the Quality of Undergraduate Engineering Programmes”, European Journal of Engineering Education, Vol. 27(4), 2002, pp 363-378.
[52] Harms P.C., Mickelson S.K. and Brumm T.J., “Using a First-Year Learning Community to Help Meet Program Objectives in Agricultural and Biosystems Engineering”, Proceedings of the 2001 American Society for Engineering Education Annual Conference & Exposition.
[53] Lengsfeld C.S. and Edelstein G., “Engineering Concepts and Communication: A Two-Quarter Course Sequence”, Journal of Engineering Education, Vol. 93(1), 2004, pp 79-85.
[54] Nera H. and Bullard L., “The Literate Engineer: Infusing Information Literacy Skills throughout an Engineering Curriculum”, Proceedings of the 2006 American Society for Engineering Education Annual Conference & Exposition.