TAKING CDIO INTO A CHEMICAL ENGINEERING CLASSROOM: ALIGNING CURRICULUM, PEDAGOGY, ASSESSMENT

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ABSTRACT

There are three major processes in education – curriculum, pedagogy, and assessment. Most reform movements focus on either the curriculum or the assessment. We believe that in order for any educational reform to be truly effective, all the three processes must reflect corresponding changes simultaneously. In fact, contemporary educational research literature strongly advises that these three processes have to be aligned in support of each other. This paper describes one approach to achieving greater alignment between curriculum, pedagogy, and assessment in a particular subject of study in a chemical engineering course at Curtin University using the CDIO framework. The paper has three sections. The first section highlights the curricular reform strategy established at Curtin University's Department of Chemical Engineering using the CDIO model. The second section describes at length how a suitable teaching and learning framework and a corresponding assessment and feedback mechanism were synthesised to reflect the aims of curricular reform. The concluding section briefly highlights the findings from a pilot study using the CDIO model undertaken in January – June 2010. This investigatory pilot study was undertaken in a final year unit called Risk Management. The preliminary findings suggest that the overall satisfaction from this unit was pleasingly very high. This has led us to conclude that from an implementation stand point the engagement of the CDIO curricular reform in the department of chemical engineering has been productive. It has enabled us to develop a coherent framework that combines teaching, learning, assessment and feedback mechanisms to address industry needs for graduates with improved competency in professional skills such as problem-solving, critical thinking and interpersonal communication skills. The classroom implementation undertaken as a pilot study has promoted the emergence of a cooperative learning environment for the achievement of unit learning outcomes. Investigation in the form of thorough unit and course evaluation will be undertaken in the near future.

KEYWORDS

CDIO Syllabus, Adapting CDIO approach, Curriculum Alignment, Learning outcomes, Learning and Teaching Framework, Assessment Methodology.

INTRODUCTION

There are three major processes in education – curriculum, pedagogy, and assessment, and according to Robinson and Aronica most reform movements focus on the curriculum and the assessment [1]. We believe that in order for any educational reform to be truly effective, all the three processes must reflect corresponding changes simultaneously. In fact, Pellegrino (cited in [2]) insists that these three processes have to be aligned in support of each other. This paper describes one approach to achieving greater alignment between curriculum, pedagogy, and assessment in a particular subject of study in a chemical engineering course at Curtin University using the CDIO framework. The paper has three sections. The first section highlights the curricular reform strategy established at Curtin University's Department of Chemical Engineering using the CDIO model. The second section describes at length how a suitable teaching and learning framework and a corresponding assessment and feedback mechanism were synthesised to reflect the aims of curricular reform. The concluding section briefly highlights the findings from a pilot study using the CDIO model undertaken in January – June 2010.

CONTEXTUALISING CDIO CURRICULUM REFORM IN CHEMICAL ENGINEERING

For well over 25 years the Department of Chemical Engineering, at Curtin University, has been engaged in preparing competent chemical engineers for work in Australia and overseas. These industry ready graduates were the result of a traditional engineering curriculum with a distinctly practical orientation. The department shares a long and rich tradition of close association with the Western Australian chemical, process, mining, and resources industries through continual consultation, research collaboration and industry-academic consortia. In 2008, the above engagement with industry affiliates revealed the expectation for graduates with even stronger problem solving, critical thinking and interpersonal skills. King's [2] report, published in 2008, *Engineers for the Future: addressing the supply and quality of Australian engineering graduates for the 21st century*, strongly echoed this demand. Hence, these warranted attention and more importantly action by the University department. Since 2008 the department has been actively engaged in exploring some recommendations of this report in its pursuit of best-practice chemical engineering education. For example, we were particularly drawn to King's recommendation that engineering educators should endeavour to explore and adopt systematic and holistic educational design practices with learning experiences and assessment strategies that focus on delivery of designated graduate outcomes based on pedagogically sound, innovative and inclusive curricula [2].

The existing traditional curriculum was no longer adequate to address the contemporary industry concerns for improved graduate competency. The need was for improved professional skills such as critical thinking, problem solving and interpersonal skills. The problem with a traditional curriculum was that it heavily gravitated toward content and knowledge acquisition. It was clear that curricular reform was necessary and timely. The emphasis of our reform would have to rest on the embedding of appropriate learning opportunities for the development of professional skills alongside mastery of disciplinary knowledge throughout the four year chemical engineering undergraduate course. With this in mind, the CDIO curricular reform model appeared a best fit owing to its equal emphasis on technical content and professional and personal skills useful to engineers. It offered us the opportunity to translate engineering skills and abilities into appropriate learning outcomes that can be addressed in specific subjects of study (or units, as they are known in the Australian educational system) within a four year engineering course.

The undergraduate chemical engineering course at the department is accredited by the Institution of Chemical Engineers (IChemE), in the U.K. The IChemE aims to recognise and share best practice in the university education of chemical and biochemical engineers [3]. It was important that the initiative to adopt the CDIO curricular reform would simultaneously endeavour to maintain our accreditation status and sustain teaching and learning standards. We found it imperative to establish a working relationship between the CDIO and the IChemE in order to proceed. In our understanding, the CDIO approach promotes the notion that learning activities are crafted to support explicit pre-professional behaviours [4]; and the IChemE's accreditation guide [3] explicitly states exactly what pre-professional behaviours can be expected of good quality chemical engineering students. The IChemE accreditation guide offered broad guidance on disciplinary content whilst the CDIO learning outcomes provided a "a pallet of potential solutions" [4] to fulfil IChemE chemical engineering degree course expectations. The next logical step in this reform process was the mapping of learning outcomes between CDIO and IChemE so as to enable a critical engagement with both. Although the results of this mapping process are available in an earlier publication by Karpe and Maynard [5], they have been reprinted here, with permission of the authors, to support the following discussion in this paper.

In Table 1 the IChemE Learning Outcome Descriptors are provided. In Table 2 the CDIO Syllabus Topics at Level 2 detail are mapped against IChemE Learning Outcome Areas (as described in Table 1). This mapping was based on the same principles used to map the CDIO Syllabus to the ABET Student Outcomes by Crawley et al [4].

Table 1
IChemE Learning Outcomes Descriptors taken from the Accreditation Guide

	IChemE Learning Outcome	Descriptors
A	Underpinning mathematics and sciences (chemistry, physics, biology)	Students' knowledge and understanding of mathematics and science should be of sufficient depth and breadth to underpin their chemical engineering education, to enable appreciation of its scientific and engineering context, and to support their understanding of future developments
	Core Chemical Engineering	Students' knowledge and understanding of the main principles and applications of chemical engineering. Areas of learning include: Fundamentals, Applied quantitative methods and computing, Process and product technology, Systems, Process safety
	Advanced Chemical Engineering (Breadth and Depth)	In terms of depth IChemE expects Masters level student with a deeper understanding than previously acquired from first exposure to a topic earlier in the degree programme, taught to Bachelor level standard. In terms of breadth IChemE expects Masters level student with exposure to topics additional to those that would normally be considered as core chemical engineering.
B	Engineering Practice Skills	Graduates must understand the ways in which chemical engineering knowledge can be applied in practice, for example in: operations and management; projects; providing services or consultancy; developing new

		technology
C	Design Practice Skills	Chemical engineering design is the creation of process, product or plant, to meet a defined need. It includes process design and troubleshooting, equipment design, product design and troubleshooting, and system design. Students develop their powers of synthesis, analysis, creativity and judgement, as well as clarity of thinking.
D	Embedded Learning (Sustainability, SHE, Ethics)	Students must acquire the knowledge and ability to handle broader implications of work as a chemical engineer. These include sustainability aspects; safety, health, environment and other professional issues including ethics; commercial and economic considerations etc.
E	Embedded Learning (General Transferable Skills)	Chemical engineers must develop general skills that will be of value in a wide range of business situations. These include development of abilities within problem solving, communication, effective working with others, effective use of IT, persuasive report writing, information retrieval, presentation skills, project planning, self learning, performance improvement, awareness of the benefits of continuing professional development etc.

Table 2
CDIO Syllabus Topics mapped against IChemE Learning Outcome Areas

CDIO Syllabus Topic		IChemE Learning Outcome
Technical Knowledge & Reasoning	1.1 Knowledge of Underlying Sciences	A
	1.2 Core Engineering Fundamental Knowledge	
	1.3 Advanced Engineering Fundamental Knowledge	
Personal & Professional Skills & Attributes	2.1 Engineering Reasoning & Problem Solving	E
	2.2 Experimentation & Knowledge Discovery	E
	2.3 Systems Thinking	C
	2.4 Personal Skills & Attributes	C, E
	2.5 Professional Skills & Attitudes	D, E
Interpersonal Skills: Team & Communications	3.1 Teamwork	C, E
	3.2 Communications	
	3.3 Communications in Foreign Languages	-
Conceiving, Designing, Implementing & Operating Systems in the Enterprise & Societal Context	4.1 External & Societal Context	C,D
	4.2 Enterprise & Business Context	B
	4.3 Conceiving & Engineering Systems	B,C,D,E
	4.4 Designing	C
	4.5 Implementing	B,D
	4.6 Operating	B,D

Once the mapping process was completed it was easier to develop an understanding of how best to incorporate the CDIO learning outcomes into various units of study across the four-year chemical engineering course. This exercise resulted in the creation of the Intended Professional Skills Progression Table (see Table 3)

Table 3
Intended Professional Skills Progression over 4-yr Bachelor degree in Chemical Engineering

	CDIO Syllabus Topic	Y2/S1	Y2/S2	Y3/S1	Y3/S2	Y4/S1	Y4/S2
Technical Knowledge & Reasoning	1.2 Core Engineering Fundamental Knowledge	Process principles	Process engineering analysis	Process modelling & simulation	Process synthesis & design	Risk Management	Design project
Personal & Professional Skills & Attributes	2.1 Engineering Reasoning & Problem Solving	3	3	3	4	4	4
	2.2 Experimentation & Knowledge Discovery	2	2	3	4	4	4
	2.3 Systems Thinking	2	2	3	3	4	4
	2.4 Personal Skills & Attributes	2	3	3	3	4	4
	2.5 Professional Skills & Attitudes	2	2	2	3	3	4
Interpersonal Skills	3.1 Teamwork	3	3	4	4	4	4
	3.2 Communications	2	3	3	3	4	4

The Intended Professional Skills Progression table is the basis of our reform strategy. The primary goal of undertaking curricular reform was to create and distribute learning opportunities for the development and refinement of professional chemical engineering skills and abilities within the disciplinary curriculum. The intention was to embed learning activities within IChemE guided disciplinary content such that student engagement with these curricular activities would provide practise of specific professional skills through achievement of CDIO learning outcomes. Our reform initiative was motivated by the need to address the industry demand for improved problem-solving, critical thinking and interpersonal skills. The left-hand side of the table incorporates specific CDIO syllabus topics we feel readily address our reform requirements. On the right-hand side of the table, core chemical engineering units of study are listed in vertical text. These units have been selected based on the IChemE guidelines for disciplinary content. Above each of these units is an indication of the year and semester in which these units will be delivered. For example, the unit, Process engineering analysis is taught in the second semester of the second year of the course; and the unit, Process modelling and simulation is taught in the first semester of the third year. In the Australian engineering education system, the first year of study is common to all engineering disciplines. This common first year, also known as Engineering Foundation Year (EFY) has a separate curriculum, distinct from disciplinary curriculum, and its design and implementation is done by different teaching and development team. This is the reason why the first year of engineering study is not included in table 3.

The numbers in the cells represent the expected student proficiency level based on the CDIO proficiency scale as suggested by Crawley et al [4]. For the purpose of clarity the rating scale linking the numbers or “scale points” to the corresponding levels of competence expected in the activities or experience of engineers is presented below.

1. To have experience or been exposed to;

2. To be able to participate in and contribute;
3. To be able to understand and explain;
4. To be skilled in the practice or implementation of;
5. To be able to lead or innovate.

Some assumptions have been made in order to arrive at these scale points within table 3. For example, it is assumed that the students entering their second year of study have had personal experiences in applying skills emphasised in the Intended Professional Skills Progression table, not just those resulting from within the context of their foundation year but also non-academic, social settings. A scale point of 2 has been chosen for personal skills and attributes of students entering year two, based on consultation with the EFY teaching and learning teams. Realistically the ability to lead or innovate will only come with several years of experience as a practicing engineer. It is much more reasonable to expect that students would graduate skilled in disciplinary practices so as to secure gainful employment. For this reason, a scale point of 4 has been chosen during the final semester of final year.

The aim of this paper is to describe how we have used the CDIO framework to approach the notion of better alignment of curriculum, pedagogy, and assessment to ensure effective curricular reform. The next logical step of our curricular reform journey was to implement the CDIO framework to examine whether our reform objectives could be sufficiently addressed in particular units of study. For this purpose, a pilot study was to be conducted in 2010, in the unit of study – Risk Management. It is taught in the first semester of the fourth year of the engineering course (see table 3). The following section describes at length how a suitable teaching and learning framework and a corresponding assessment and feedback mechanism were synthesised to achieve the aims of curricular reform using CDIO.

LEARNING, TEACHING, ASSESSMENT, FEEDBACK: SYNTHESIS OF A SOUND FRAMEWORK

Robinson and Aronica [1] believe that most educational reforms focus either on curriculum or on assessment. They contend that these reforms fail because the policy makers believe that in education the best way to face the future is by improving what they did in the past. What this means is that, for example, ineffective assessment reforms are succeeded by more assessment reforms. Not enough attention is given to all the components that comprise the educational system. Stark and Lattuca (cited in [6]) draw our attention to the fact that what we call the curriculum is in fact a complex phenomenon. They appeal for the recognition and exploration of the interdependence of the elements within this complex phenomenon. It is important here to unpack the implications of Stark and Lattuca's appeal. What are the elements of a curriculum? In what way are they interdependent? We felt it was important to understand the elements of an engineering curriculum and how they are interrelated because it would better enable us to determine the most appropriate course of action to take reform straight to where it mattered most, the engineering classroom. Cornbleth (cited in [6]) reminds us that our conceptions and ways of reasoning about curriculum reflect and shape how we see, think, and talk about, study and act on the education made available to our students. Cornbleth's statement validated our decision to better understand the elements of the engineering curriculum we were keen to reform.

Curricula in higher education are, to a large degree, hidden curricula, being lived by rather than being determined [7]. According to Barnett, curricula have an elusive quality about them; their actual dimensions and elements are tacit; they take on certain patterns and relationships but those patterns and relationships will be hidden from all concerned, except as they are experienced by the students [7]. What does this mean? In the contemporary educational context the curriculum is something that the educational institution concerns itself with. The course leaders of the institution design the curriculum. This curriculum is then experienced on a daily basis by the subjects of the institution, its enrolled students. This experience takes the form of classroom interactions and other specifically designed learning activities which address certain learning outcomes. Student engagement with learning outcomes leads to the fulfilment of curricular intentions. In reality though, it is never so simple. Curricular intentions take the form of broadly defined graduate attributes, or more particularly, refined explicit learning outcomes for specific units of study. But having a well-designed curriculum or well-stated learning outcomes is only a small part of successful education practice. The eventual success of the curriculum rests largely in what happens within classrooms. This is where the elements of this hidden curriculum co-mingle and give rise to the complexity of teaching and learning disciplinary knowledge and skills.

Let us take a moment to understand what this means. It is important to note that educational institutions emphasising knowledge and skills acquisition are largely prevalent. But Dall'Alba and Barnacle point out the curricula designed by these institutions raises the question of how such knowledge and skills are to be integrated into skilful practice, or more broadly, contribute to the transformation of the learners [8]. Dall'Alba and Barnacle believe that students are not assisted and supported in situating and localising knowledge within specific manifestations of practice; a focus on knowledge acquisition leaves to students the difficult task of integrating such knowledge into practice [8]. In other words, whilst the university (or school or department) expects students to engage in the acquisition of disciplinary knowledge, principles and concepts, there is little promotion of *how* to actually learn such complex domain knowledge, appreciate it, and subsequently effectively apply it. What is the implication of the above statements in our context? Our curricular reform must not only expect the students to improve their problem-solving, critical thinking and interpersonal skills, but also attempt to establish and elaborate what this actually entails, and how these can be exercised. It is the department's responsibility to provide organisational and cultural support for learning oriented practices involved in the development of professional engineering skills.

Claxton identifies that the key to educational reform lies in the culture as it is experienced, day in, day out, by the students [9] He recommends that real reform actually needs to take place in the classroom ethos and methods, and the assumptions that underpin them. In our understanding, Claxton is suggesting that curricular reform needs to affect the culture of learning, teaching, assessment and feedback within the classroom. These form the elements of the curriculum that interplay within the everyday classroom environment. A survey of contemporary higher education literature will confirm that these represent the visible dimensions of any hidden curriculum.

Ritchhart (cited in Claxton [9]) makes a pithy observation, which we personally identify with:

> "We've come to mistake curricula, textbooks, standards, objectives, and tests as ends in themselves, rather than as means to an end. Where are these standards and objectives taking us? What is the vision they are pointing toward? What purpose do they serve? What ideals guide us?...Without ideals, we have nothing to aim for. Unlike standards, ideals can't be tested. But they can do something standards cannot: they can motivate, inspire and direct our work."

We felt these are questions worth considering in our endeavour to adopt the CDIO standards and model. Why did we concern ourselves with educational reform? Our personal response to this question is: Learning does matter; and so do our Learners. The act of learning is meaningful and productive only if the learner willingly engages in it. Savin-Baden observes that for those of us who have designed courses that enable students to meet the learning outcomes expected by benchmarking standards, the university and the professional body the challenge then is to equip the students to take up the challenge of taking control of their learning [10]. The IChemE believes that chemical engineering education needs to stimulate and develop student talents and that the university degree programmes must communicate the relevance and excitement of our profession [3]. The IChemE concedes that high quality chemical engineering degrees are demanding on students [3]. We agree with this view. It is also the reason why we share Savin-Baden's previous sentiment about challenging students to take engage in self-directed learning. Without passionate self-directed engagement in learning, such high expectations will merely prove to be onerous, not just for the students but also those enthusiastic educators who facilitate quality learning. For, little of value is achieved without effort, although a great deal more is achieved with impassioned effort. The reason we're pursuing the CDIO curricular reform is so that it may be "enthuse, engage and inform students" [11], and that the learning activities can possibly enhance our students' "relationship to their learning and the content they are learning about" [12].

How do we promote self-directed learning? Robinson and Aronica believe that it is possible when we put students in an environment where they want to learn [1]. Dewey (cited in [13]) recommends that when we give students something to do, not something to learn; and the doing is such a nature as to demand thinking, or the intentional noting of connection; learning naturally occurs. Keeping this recommendation in mind, our next question focused on what type of learning by doing would be appropriate for the study of Risk Management. The nature of this disciplinary domain would reveal our answer. The IChemE accreditation guide recommends that this topic be considered integral to the study of chemical engineering systems, and expects students must be able to understand the principles of risk and safety management, and be able to apply techniques for the assessment and abatement of process and product hazards [3]. Risk Management textbooks suggest how the subject ought to be engaged for the purposes of learning. Cameron and Raman propose that an undergraduate introductory course needs to emphasise principal concepts of risk management and the practical outworkings of those concepts [14]. Skelton deems it necessary to show undergraduates how safety assurance is actually performed in industry [15]. Skelton recommends that students move gradually from simple application of common sense and basic engineering skills to application of specialist safety analysis methods [15]. Based on the above recommendations it was determined that learning within this unit of study be distinctly application oriented. It was to provide ample opportunities for students to mobilise their thinking skills, transfer and apply prior knowledge such as vacation work experience and internship, engage and exercise their engineering sensibilities and powers of judgement, and actively make connections between chemical and process engineering theory and practice in the context of real-world scenarios and situations.

Using the Intended Professional Skills Progression table (see table 3) as a reference and combining the IChemE guidelines and Risk Management textbooks recommendations we chose specific CDIO syllabus topics that could be addressed through appropriate learning activities. Table 4 provides a mapping of the Risk Management Unit Learning Outcomes to their corresponding CDIO syllabus topics at levels 1, 2 and 3.

Table 4
Definition of Risk Management Unit Learning Objectives (ULOs) mapped to corresponding CDIO Syllabus topics at Level 1, 2, and 3.

Unit Learning Outcome	CDIO syllabus topic at level 1	CDIO syllabus topic at level 2	CDIO syllabus topic at level 3
Risk Management Principles and Concepts	Technical Knowledge and Reasoning	Core Engineering Fundamental Knowledge	-
Reasoning and Problem Solving	Personal & Professional skills and attributes	Engineering Reasoning and Problem Solving	• Problem Identification & Formulation • Estimation and Qualitative Analysis • Solutions & Recommendations.
Knowledge Discovery	Personal & Professional skills and attributes	Experimentation and Knowledge Discovery	• Hypothesis Formulation • Survey of Print and Electronic Literature • Hypothesis Test, and Defence.
Systems Thinking	Personal & Professional skills and attributes	Systems Thinking	• Thinking Holistically • Emergence & Interactions in Systems • Prioritization & Focus
Critical Thinking	Personal & Professional skills and attributes	Personal Skills and Attributes	• Critical Thinking • Awareness of One's Personal Knowledge, Skills & Attitudes • Lifelong Learning
Teamwork	Interpersonal Skills	Teamwork	• Team Operation
Communication	Interpersonal Skills	Communication	• Communication Structure • Oral Presentation and Inter-personal Communication

How does this table help us in the classroom context? The CDIO concept promotes the notion that learning activities can be crafted to support explicit pre-professional behaviours [4]. The unit learning outcomes represented on the left-hand side of table 4 highlight the knowledge and skills we consider relevant for effective study of Risk Management. Activities involving the CDIO syllabus topics at level 3, on the right-hand side, can then be crafted to achieve the corresponding unit learning outcomes. For example, activities emphasising problem identification, solutions and recommendation can be designed to address the unit learning outcome relating to engaging reasoning and problem-solving skills. It is also possible to design activities that address more than one unit learning outcome at the same time. For instance, students can operate in small teams to undertake a hypothesis defence for a particular problem scenario. Teams can engage in oral presentations with other teams to argue and defend their respective hypotheses.

For the purposes of this unit, the problem-based learning approach was considered most conducive to facilitate effective engagement with the specific CDIO level 3 syllabus topics. PBL proponents and practitioners have published extensively about its benefits including its ability to develop professional competencies, higher order thinking skills, interpersonal skills, and an understanding of how to apply knowledge, and hence improve quality of learning [16-23].

Bearing in mind the unit learning outcome and the corresponding CDIO level 3 syllabus topics, appropriate learning activities were determined. These learning activities could be favourably grounded in the problem-based learning approach. The chosen learning activities and their theoretical rationale based on contemporary educational research literature is represented in Table 5.

Table 5
Risk Management Learning Activities and their Theoretical Rationale

Learning Activity	Rationale
• Homework problem • In-class group problem • In-class test	• Learning starts with and occurs through engagement with authentic ill-structured problems [16].
• Reflective Journal for Food for Thought	• Learning processes of enquiry which proceed by asking what needs to be known to address and improve a particular situation [20]. • Critical reflection is central to effective action [20].
• Concept Map	• Assisting students to visualise the structure of the subjects they study, that is, the links between concepts [24].
• In-class group-facilitator discussion on Food for Thought • In-class group-to-group presentation on In-class group problem • In-class group-to-class presentation with question-time, and facilitator feedback • In-class group-to-group peer feedback on presentation	• Fostering community through group work [25]. • Learn how to interact with different people and systems and learn to rely on their advice and knowledge [26]. • Opportunities to get learners to evaluate reasoning [27]. • To make visible to students to see the ontological, epistemological and methodological dilemmas [27] involved in resolution of authentic ill-structured problems.

In this unit of study all the learning activities were deemed assessable. This strategy acknowledged two important educational research recommendations. The first being that assessment is fundamental to the teaching process and that the time during assessment could and should be used as an excellent time for learning [24]. The second recommendation promotes the notion that the process of assessment provides a natural opportunity to bring both content and process objectives together and that process skills can be demonstrated and assessed as an integral part of assessing content knowledge [18]. Table 6 provides an indication of how each individual learning activity can provide address specific unit learning outcomes in Risk Management. For example, the homework problem will require engagement of disciplinary knowledge, reasoning and problem solving, and knowledge discovery skills. The in-class group presentation activity will effectively engage reasoning and problem-solving using disciplinary knowledge and team operation and communication skills.

The learning activities were interactive. This way it was possible for the facilitators (lecturers and tutors) to provide immediate feedback to students in most cases. Learning requires feedback [28]. Our stance on providing feedback was based on a sound recommendation by

Price, Handley, Millar and O'Donovan that in an environment espousing a focus on the development of independent thinkers, feedback can only be positioned as advice rather than instruction [29]. Table 7 presents our feedback mechanism for Risk Management.

Table 6
Risk Management Unit Learning Outcomes mapped to Learning Activity/ Assessment Type

Unit Learning Outcome	CDIO Syllabus Topic Level	Homework Problem	Reflective Journal	Group Problem	Group Presentation	Concept Map	Test
Risk Management Knowledge	1.2	X		X	X	X	X
Reasoning & Problem solving	2.1	X		X	X		X
Knowledge Discovery	2.2	X		X			
Systems Thinking	2.3		X	X		X	X
Critical Thinking	2.4.4			X			X
Lifelong learning	2.4.6		X			X	
Teamwork	3.1.2			X	X		
Communication	3.2.2 3.2.6		X	X	X		X

Table 7
Feedback Mechanism for Risk Management

Rationale for Feedback	• Feedback can only be positioned as advice rather than instruction [29]. • Students' ability to make sense of and use feedback can be improved through classroom discussion of improvements students intend to make [28].	
Learning Activity	**Time of Feedback**	**Method**
Food for Thought	Weekly, in-class	Dialogic, group-facilitator interaction
Reflective Journal	Weekly, in-class	Written, and dialogic (if appropriate)
In-class presentations	Weekly, in-class	Written, and dialogic, in the form of peer and facilitator responses
In-class tests	In-class feedback sessions a fortnight after each test	Dialogic, and written (available upon student request)
Concept Map	Currently we are unable to provide sound feedback. A concept map analysis software is under investigation to generate useful insights on student learning.	

REFLECTIONS AND FINDINGS

According to Boud (cited in [30]), at the end of the day what makes a difference is exactly what a student does and how they experience what they do. In February-June 2010 a pilot study was undertaken to implement the CDIO model within a chemical engineering unit of study named Risk Management. We had a class with 133 enrolled students. In the course of implementing our approach we encouraged students to engage in providing us on-going feedback on the teaching and learning experience. During the semester spanning 14 weeks with an actual teaching period of 12 weeks, we secured this quality-as-experienced feedback in week 4, 12 and 14 in the form of student learning satisfaction questionnaires and unit evaluation surveys. The student learning satisfaction questionnaire was designed by the second author, whilst the unit evaluation survey is a university designed instrument named “eVALUate”. The response rate for the student learning satisfaction questionnaire was 100% since all the enrolled students (133) attended the final class in week 12 and willingly shared their views on the learning experience. The response rate for the eVALUate is 42% since these are collected at the end of the semester at which time a majority of the students are either unavailable or uninterested in any university related activities until next semester. It is beyond the scope and intent of this paper to examine and analyse the effectiveness of our approach. The preliminary findings suggest that the overall satisfaction from this unit was pleasingly very high. Most students appreciated the interactive learning activities such as group discussions and found the group presentations beneficial. Concerns were raised regarding the utility of concept maps and reflective journals as learning tools. Some students found traditional pedagogic methods better suited to cover technical aspects of this unit of study. This could be attributed to differences in learning styles, motivations, or resistance to alternative methods that demand heavier learner engagement. A large majority of students found the homework and group problems as effective means to learn in this unit. Most students were receptive to the fact that the unit’s learning activities encouraged active thinking. A vast majority of the students strongly appreciated the feedback they were receiving throughout the learning experience and how it was helping them understand the unit better.

The preliminary findings led us to conclude that engagement of the CDIO curricular reform in the department of chemical engineering has been productive. It has enabled us to develop a coherent framework that combines teaching, learning, assessment and feedback mechanisms to address industry needs for graduates with improved competency in professional skills such as problem-solving, critical thinking and interpersonal communication skills. The classroom implementation undertaken as a pilot study has promoted the emergence of a cooperative learning environment for the achievement of unit learning outcomes. Investigation in the form of thorough unit and course evaluation will be undertaken in the immediate future.

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