WRITING CLEAR CUSTOMIZED LEARNING OUTCOMES WITH KEY UNDERPINNING KNOWLEDGE

Dennis Sale
Sin-Moh Cheah
Singapore Polytechnic

ABSTRACT
This paper is based on Singapore Polytechnic's (SP) experience in implementing the CDIO approach and standards for pilot diploma courses across four academic schools. It documents the approach taken to customize CDIO to a polytechnic context. A specific focus on a chemical engineering module is used by way of example to model the systematic infusion of selected CDIO skills.

In order to produce a fully aligned curriculum at module level, a subject specialist and lecturer for the module working with SP's Senior Education Advisor used the following approach:

- Modelling and unpacking the module syllabus to identify specific topic areas in which the infusion of selected CDIO skills (e.g., Personal Skills and Attitudes, Interpersonal Skills: Teamwork and Communication, etc) would naturally support the learning of subject content knowledge and skills
- The production of appropriate assessment items and scoring systems
- Designing the learning experience and activities to make the module as interesting and real world as possible, within the particular environmental and resource constraints.

Finally, the paper identifies the main problems and challenges faced in the curriculum innovation, the ways in which they were tackled and key lessons learned from the overall experience to date.

KEYWORDS
Curriculum, Syllabus, Objectives, Learning, Knowledge

INTRODUCTION

Defining curriculum outcomes is essentially concerned with addressing the question of what skills, knowledge and attitudes are most useful to attain and for what purpose. In the specific context of engineering education, the issue of curriculum outcomes is captured by Crawley et al (2007):

> What is the full set of knowledge, skills, and attitudes that engineering students should possess as they leave the university, and at what level of proficiency? (p.34)

However, in engineering, as in most curriculum areas, we are being faced with an increasing major planning dilemma. On the one hand we are experiencing an exponential growth in subject content knowledge (Neff et al.,1995). Furthermore, they point out that engineering is also becoming increasingly specialized and changes rapidly. Simply tinkering with the content curriculum, adding, deleting, rationalizing, etc. cannot address this problem, and it can only get worst. At present, there is great pressure on many lecturers to cover more content in shorter time frames via compressed modules and various support technologies, from handouts to virtual colleges.

On the other hand, we are expected to provide graduates who not only have a viable technical competence, but also a range of social and teamwork competencies, and a disposition for flexible lifelong learning.

In the present societal context of rapid change, unpredictability and a potentially volatile future, we are both swamped with knowledge possibilities and confusion about what are the most important human qualities and attributes to foster, both for the world of work and effective citizenship. Quite simply, we cannot fully know what abilities or competencies will be most useful for future society. Curriculum planning must, therefore, recognize the systemic and accelerating nature of change and build the necessary flexibility into the curriculum format and learning process.

DERIVING SPECIFIC LEARNING OUTCOMES

The CDIO Skills framework was the product of a comprehensive stakeholder focus group exercise comprised of engineering faculty, students, industry representatives, university review committees, alumni, and senior academicians. The resulting CDIO Syllabus classifies learning outcomes into four high-level categories:

1. Technical knowledge and reasoning
2. Personal and professional skills and attributes
3. Interpersonal skills: teamwork and communication
4. Conceiving, designing, implementing, and operating systems in the enterprise and societal context.

These high level categories are further subdivided and organized into four discrete rational levels. While levels 1 & 2 are generic and specified, the selection of level 3 & 4 learning outcomes and the level of proficiency is within the framing of individual educational institutions, customized to the course context and stakeholder needs. The recommended process for establishing proficiency levels and learning outcomes is as follows:

- Review the generic CDIO Syllabus and make modifications or additions to customize it for a specific course of study within the technical and national context of the program.
- Identify and survey the important stakeholders of the program – both internal and external to the university – and validate their coverage and proficiency level to the local context
- Write specific learning outcomes that guide the design of learning and define the assessment requirements

This we felt was a critical process for the success of the curriculum innovation. Limitations in the appropriateness, clarity and currency of the learning objectives inevitably run through the instructional and assessment systems. There’s limited value in teaching and assessing a knowledge or skill area in effective and efficient ways if it has little or no relevance to stakeholder interests.

Furthermore, as Diamond (1998) points out:

> …it is a major mistake to take any published list of basic skills or competencies and accept it for use on another campus without revision. Not only will the specific items on such a list vary from institution to institution but the definition of each item will vary as well. The final list of competencies, their definitions, and how they should be assessed must evolve on each campus. Faculty ownership in the process is an essential element for success. (p.53)

In order to ensure that the CDIO skills at levels 3 & 4 were most appropriate to the context of students at Singapore Polytechnic a working group of representatives from the various engineering schools was established to systematically work through all the CDIO Skills, with a remit to:

- Identify which skills were most appropriate in the SP context
- Decide a viable proficiency level
- Write specific learning objectives that are measurable at level 4

It must be noted that this is a time consuming process as faculty have different frames about what skills should be included, the level of proficiency deemed viable and the actual statements of specific learning outcomes. Our approach was to spend the necessary time to get the best consensus as possible. While this resulted in a large number of meetings and iterations, in the longer run, it is time well spent. Individual schools are at liberty to customize objectives at level 4 to the specific engineering context where appropriate, providing there is no change in the knowledge domain covered, cognitive activity involved and proficiency level. The customized selected CDIO skills (e.g., Personal Skills & Attitudes; Interpersonal Skills: Teamwork & Communication) are presented in Appendix 1.

USING THE CONCEPT OF INFUSION FOR INTEGRATING CDIO SKILLS

In integrating CDIO Skills with the technical content we modelled the infusion approach of Swartz (1987). The infusion approach argues that generic process skills such as thinking are best learned through "conceptual infusion" with the subject content. This involves identifying the ingredients of good thinking - "the skills, competencies, attitudes, dispositions, and activities of the good thinker"- and designing these into the structure of the lesson content (p.125). The essential point is that the thinking processes and skills mutually develop the meaningful acquisition of knowledge to form understanding.

The infusion approach effectively resolves, or at least mitigates, the debate over how much content and process should be included in a curriculum offering. While there is, of course, no universal answer to this question – it is always a question of what learning outcomes are deemed most relevant in a situated context. However, there is virtual agreement among cognitive psychologists that effective thinking - however defined - needs an extensive and well organized knowledge base. As Resnick (1989) summarizes:

> Study after study shows that people who know more about a topic reason more profoundly about that topic than people who know little about it. (p.4)

Similarly, Satinover (2001), drawing from recent brain research makes the case for the importance of repetition in the learning process:

> …these mundane chores are precisely what turns the fourth brain from a mass of randomness into a intellect of dazzling capacity. "Genius," according to Thomas Edison, "is one percent inspiration and nine-nine percent perspiration. Of "critical thinking skills," he had nothing to say. (p.49)

However, while thinking is only developed when thinking about something, knowledge is only made meaningful through thought. As Paul (1993) strongly argues:

> Thought is the key to knowledge. Knowledge is discovered by thinking, analyzed by thinking, organized by thinking, transformed by thinking, assessed by thinking, and, most importantly, *acquired* by thinking. (vii)

Our approach, therefore, was to recognize the range of important components of effective learning and derive a pedagogically sound and viable structure for the infusion of CDIO Skills. In the specific case of 2.4 'Personal Skills & Attitudes', for example this has involved identifying where in the subject content exist the richest opportunities to infuse the desired thinking and learning skills.

In order to achieve this it is firstly essential to work closely with subject specialists, modelling the content and identifying the real work performances that students would be expected to do on successful completion of each module. A major outcome of this initial modelling process has been that the curriculum outcomes have been refocused towards a more performance or competency-based focus. Many of the modules contained a preponderance of 'knowledge' and 'comprehension' based learning outcomes – based on Blooms Taxonomy (1956), which is used as the basis for writing learning outcomes in SP.

Once the curriculum objectives are framed more towards a performance-based emphasis rather than knowledge recall, it focuses attention on the real world applications of the module content. From this basis, it is possible to use cognitive modelling of the key activities to identify the types of thinking that underpin highly effective performance. This is typically achieved by firstly asking the subject specialists (in this case academic faculty) to make explicit their thinking in relation to the following question:

> How would a highly competent person think in the effective execution of this activity?

A useful technique to facilitate this is to visualize the activity and try to systematically describe the stages and types of thinking involved in conducting it effectively. For many lecturers this took some time initially and is most profitably done in a small group of similar subject specialists. The difficulty is that experts, in any field, usually take for granted the types of thinking involved as these becomes tacit and unconscious over time. However, as in learning to do anything, with the right input, guidance and practice, competence develops.

Using this technique in relation to the 'Chemical Reaction Engineering' module, we were able to identify the specific types of thinking that underpinned competence in the various topic areas. To illustrate, in 'Obtaining the Rate Law for specific chemical reactions', the following are examples of specific level 4 learning outcomes:

- Infer and interpret experimental data on the effect of temperature on the rate of chemical reactions
- Compare and contrast the integral and differential methods of analysis in rate law determination.
- Use integral and differentiated methods of analysis to determine the rate law for a liquid reaction

In using this approach it became possible to identify the types of thinking and learning skills that were naturally supporting of achieving proficiency in the subject knowledge and skill areas. From this process it became possible to provide systematic guidance in helping faculty to:

1. Review existing module aims and learning objectives to identify the real world activities that students would be expected to do as a result of successfully completing the module.
2. Identify the types of thinking and other learning skills essential for highly competent performance in these real world activities
3. Write learning outcomes that specific cued the types of thinking in relation to knowledge acquisition. The following are examples from across engineering programmes:
    - Predict the impact of pollution on water quality
    - Compare and contrast a range of retaining structures
    - Evaluate food packaging techniques to advise on use for specified food products
    - Generate new design options for marketing a health food product

Similarly, it was a fairly straightforward process to infuse other CDIO skills such as communication and teamwork into modules. Where such skills can be naturally built into the learning designs (including activities) there are viable possibilities for inclusion as level 3 and 4 learning outcomes. Again, for Chemical Reaction Engineering, a significant component of the learning activities required students working in groups. This is a naturally occurring learning opportunity to include selected ‘Teamwork’ and related ‘Communication’ learning outcomes, such as:

- Identify the components of an effective team
- Identify team roles and their impact on team performance
- Apply team ground-rules and display teamwork (including leadership) in a range of team role situations when conducting experiments
- Design appropriate communication strategies for presenting experimental findings
- Demonstrate effective oral communication in presenting experimental findings

It is also necessary to plan the integration of specific skills within the curriculum structure to ensure sufficient logical development of the competence, as well as ensuring resource-effectiveness in both the learning and assessment process. For example, if ‘good thinking’ is to be developed over the duration of the curriculum, then it will be important to have structured development of such sub-skills as ‘generating possibilities, analysis, comparison & contrast, inference & interpretation, evaluation’ and metacognition. As Marzano (1988) points out:

> ... we can improve students’ ability to perform the various processes by increasing their awareness of the component skills and by increasing their skill proficiency through conscious practice. (p.65)

THE IMPORTANCE OF UNDERPINNING KNOWLEDGE

Having produced the customized CDIO syllabus for SP, we were well aware that teaching and assessing certain skills would pose significant challenges for many engineering faculty. Firstly, some engineering faculty question the rationale for teaching such skills as contained within Personal & professional Skills & Attributes, as well as Interpersonal Skills: Teamwork & Communication. Most significantly, is it their responsibility to teach these skills? After all, we already have certain institutional models and electives that cover many of these skill areas. Furthermore, are we not already overburdened with the demands of the technical engineering curriculum – not to mention the increasing plethora of administrative work that is now the norm in most educational institutions?

Secondly, and equally important, are faculty fully equipped to teach these skills effectively and efficiently? Many of these skills involve key knowledge from the fields of psychology, economics and, some would say, philosophy. The issue of whether all engineering faculty should be capable of teaching such CDIO Skills is significant. Is it preferable and more viable for a specialist service department, who teach language and communication, to take the main responsibility for teaching skills like teamwork and communication, leaving engineering faculty to reinforce where necessary?

However, what is crucial is the identification and delineation of the key underpinning knowledge for each of the CDIO skills, particularly those that engineering faculty may feel less familiar with (e.g., Personal & professional Skills & Attributes, as well as Interpersonal Skills: Teamwork & Communication., Systems Thinking).

The production of clear, concise underpinning knowledge is really important to facilitating ‘buy in’ from faculty. Once they fully understand what is involved and the importance of these skills for student learning, they are less resistant to the idea that they might need to teach it. Most significantly, they quickly appreciate that much of the underpinning knowledge – especially in the area of teamwork and communication – is, in fact, very familiar to them. This is not surprising, as we would expect experienced engineering professionals to possess such knowledge and related competence. However, such knowledge is typically tacit (Polanyi, 1967) rather than explicit. Through the explicit provision of key underpinning knowledge for CDIO Skills, it is possible to bring such tacit knowledge to an explicit focus. Faculty can then see that they actually possess such knowledge and competence. It is then much easier for them to make direct connections to where and when in the curriculum such skills can be naturally and effectively integrated. Table 1 illustrates the 4 levels of CDIO outcomes as well as an example of underpinning knowledge relating to ‘Identify the components of an effective team’.

Table 1

3	**INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION**
	TEAMWORK (learning Outcomes) ***Form Effective Teams*** Identify the components of an effective team Identify the stages of team formation Identify team-roles and their impact on team performance Analyze the strengths and weakness of a team
UNDERPINNING KNOWLEDGE ***Identify the components of an effective team*** • The key components/attributes of successful teams (e.g., shared vision/goals, commitment of team members to agreed vision/goals, principled leadership, open communication, collaborative climate, competent team members, and desire to achieve high standards of performance). How these components/attributes result in effective teamwork in a range of situations (e.g., work team, social team, family. The consequences of a lack of these components/attributes for effective team functioning. • How effective teams create 'synergy', which is a major benefit of good team-working. The performance of such teams is more than the sum of the individual's competences within it. How high performing teams maximize the strengths of members, neutralize weaknesses and generate new ideas and strategies from their collective knowledge and competence.	

ALLIGNING CURRICUM COMPONENTS

In producing valid and resource effective assessment methods and instruments, as well as appropriate learning designs and instructional strategies, we followed the essential principles of curriculum alignment. For example, the assessment methods must validly assess the knowledge components, skills and attitudinal aspects of specific learning outcomes. In cases where complex performance (incorporating the integration of concepts, types of thinking, communication skills, etc) was to be assessed, authentic real world tasks were designed to provide such assessment and learning opportunities. The learning designs (incorporating activities) were similarly calibrated in the alignment process.

For Chemical Reaction Engineering, a summary performance-based task is presented in Table 2.

Table 2

Study of Temperature Effect on Reaction Rate using CSTR
<u>Task Scenario</u> Your team members are employees of a chemical manufacturing company, *All Safe Chemicals Pte Ltd*. Your company recently installed a new chemical reactor pilot plant for the purpose of investigating how temperature affects the rate of reaction of various chemical reactions. The pilot plant is a continuous stirred tank reactor (CSTR) controlled by PlantScape (a SCADA or supervisory control and data acquisition software). Today, the reaction of interest is the <u>saponification</u> between sodium hydroxide and ethyl acetate.
<u>Objective</u> Your team has been assigned the following task: To study the effect of temperature on rate constant using the Arrhenous Law; by determining the Arrhenius parameters, i.e. activation energy (E_a) and frequency factor (k_o).
<u>Pre-Experiment Preparation</u>: Forming a Team and Allocation of Roles Divide the workload among your team members to take on the following roles: 1. Supervisor – overall coordination to ensure that procedures are being followed, proper safety precautions are taken 2. Panelman (or Boardman) – monitor the progress of the experiment via PC 3. Senior Technician – monitor proper functioning of conductivity meter and level control system 4. Technician Grade I – perform plant line-up, waste disposal (as and when needed), washing

Using a range of performance-based tasks both acts as a means of structuring the integrated learning experience as well as providing more authentic assessment opportunities. In this way, as Perkins (1992) suggests, “Teaching, learning, and assessment merge into one seamless enterprise” (176).

CHALLENGES FACED AND LESSONS LEARNED – SO FAR

> Curriculum can be seen as the battlefield of many competing influences and ideologies. (Kelly, 1995, p. 149)

> ...the central problem of curriculum study is the gap between our ideals and our attempt to operationalize them. (Stenhouse, 1989, p.3)

Essentially, many of the challenges faced are those typical of large scale educational or curriculum innovations. Change by its very nature is usually contested in terms of stakeholder interests and perceptions of worth. Furthermore, lecturers (and teaching professionals across most educational sectors) have seen many a curriculum initiative come, and go. It is hardly surprising that the introduction of CDIO faced similar reactions to what has gone before in terms of proposed institutional curriculum change. Sallis and Hingley's assertion (1991) that "education is a creature of fashion" (p.9) is pertinent in this context.

It was especially important, therefore, not to introduce CDIO as a quick fix for motivating students or a new way of 'doing engineering education'. Much time has been spent in looking critically at the CDIO approach, comparing what is involved in its implementation in relation to what we are already doing (at least in a significant number of areas by segments of the lecturing force).

Furthermore, and perhaps most important in the long run, assessing the face validity of what is being proposed in CDIO Standards relating to the design, management and assessment of student learning. In most basic terms, we invite faculty to consider the worth of such an approach to engineering education. The notion of making engineering education more real life focused and interesting is a hard one to take serious issue with. However, trying to do too much too quickly is always a recipe for disaster in any change context – education or otherwise. This we feel has been a strength in our approach so far. By selecting a limited number of CDIO skills for inclusion into course and module syllabi, as well as the thoughtful translation of these competency areas into realistic clear and customized level 3 and 4 learning outcomes to the polytechnic context has proved to be well founded. We are trying hard to reduce both cognitive load as well as workload for already busy lecturers.

Invariably, moving beyond the existing project team and selected lecturing staff involved in the innovation will present challenges in terms of providing necessary and sufficient staff development support. It is really important to ensure that we capture good practices in terms of curriculum materials (e.g., customized learning outcomes, assessments and learning designs) from which others can model and utilize where appropriate. Many approaches may be utilized to supporting lecturers as we work through the various CDIO Standards, helping them to develop the range of competences necessary for this challenging professional teaching role. An approach suggested by Darling-Hammond & Bransford (2005) is likely to be appropriately customized to the polytechnic context as a useful framework for knowledge building and sharing good practices and resources.

> Emerging evidence suggests that teachers benefit from participating in the culture of teaching – by working with the *materials and tools of teaching practice*; examining teaching plans and student learning while immersed in theory about learning, development and subject matter. They also benefit from *participating in practice* as they observe teaching, work closely with experienced teachers, and work with students to use what they are learning. (p.404)

References

Bloom B., Taxonomy of Educational Objectives, Longman, London, 1956.

Crawley E. F. (Ed.), Rethinking Engineering Education: The CDIO Approach, Springer, New York, 2007.

Darling-Hammond L. & Bransford J., Preparing Teachers for a Changing World: what teachers should learn and be able to do, Jossey-Bass, San-Francisco, 2005.

Diamond R. M., Designing & Assessing Courses & Curricula: A Practical Guide, Jossey-Bass, San Francisco, 1998.

Kelly A. V., The Curriculum: Theory and practice. Paul Chapman, London, 1989

Marzano R. J. et al., Dimensions of Thinking: A Framework for Curriculum and Instruction, ASCD, Alexandria, VA, 1988.

Neff G. et al., "Transforming Engineering Education from a Product to a Process". A paper presented at the 4th World Conference on Engineering Education, 1985, 15 - 20 October, Saint Paul Minnesota, USA, Vol 1. pp.5-9.

Paul R. W., Critical Thinking, Foundation for Critical Thinking, Santa Rosa, CA, 1993.

Perkins D. N. Smart Schools, The Free Press, London, 1992.

Polanyi M. The Tacit Dimension, Routeledge and Kogan Paul, London, 1967.

Resnick L. B. "Assessing the Thinking Curriculum: New Tools for Educational Reform.' in B. R. Gifford & M. C. O'Connor (Eds.)", Future Assessments: Changing views of aptitude, achievement, and instruction, Kluwer Academic Publishers, Boston, 1989.

Sallis E. and Hingley P., "College Quality Assurance Systems", Mendip Paper D20, Coombe Lodge, Bristol, 1991.

Satinover J., The Quantum Brain, John Wiley and Sons, Inc, New York, 2001.

Stenhouse L., An Introduction to Curriculum research and Development, Heinmann Educational Books, Oxford, 1989.

Swartz R. J., "Teaching for Thinking: A Developmental Model for the Infusion of Thinking Skills into Mainstream Instruction" in Baron, J. B and Sternberg, R. J. (Eds.), Teaching Thinking Skills: Theory and Practice. Freeman, New York, 1987.

Biographical Information

Dennis Sale is the Senior Education Advisor at Singapore Polytechnic. He has worked across all areas of the British educational system and provided a wide range of consultancies in public and private sector organisations in the UK and several Asian countries. Over the past 20 years Dennis has been extensively involved in training, coaching and assessing teaching professionals. He has developed original approaches to promoting thinking in the curriculum and how to develop creative teaching competence. These have been widely presented at international conferences and published in a variety of journals and books.

Dennis Sale can be contacted at:

Educational & Staff Development Department
Singapore Polytechnic
500 Dover Road
Singapore 139651

Tel: 65 6772 1490
Email: dennis_sale@sp.edu.sg

Sin-Moh Cheah is the Deputy Director and Course Chairman of the Diploma in Chemical Engineering at the School of Chemical & Life Sciences, Singapore Polytechnic. He oversees the management of the Diploma and lectures on Chemical Reaction Engineering and Separation Processes. He holds a B. Eng (Chemical) 1st Class Hons from the National University of Singapore. He previously worked as Process Engineer, Project Engineer and Process Planner at Mobil Oil Singapore Pte Ltd.

Appendix 1

2. PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES

2.4 Personal Skills and Attitudes

2.4.1 Apply the thinking process

Use a range of critical thinking skills (eg analysis, comparison and contrast, inference and interpretation, and evaluation)
Identify the creative thinking process (e.g. generating possibilities, incubation, illumination, etc)
Use a range of creative thinking tools and techniques (eg Brainstorming, Mindmapping, TRIZ)
Identify contradictory perspectives and models
Reframe and take a range of different perspectives
Use metacognition in monitoring the quality of personal thinking

2.4.2 Analyze factors that affect thinking

Identify barriers to effective thinking (e.g., traits, dispositions, working memory, perception, lack of information, etc)
Identify factors that promote effective thinking (motivation, trust, openness, risk taking, exposure to varied knowledge bases and ideas, etc)

2.4.3 Manage Learning

Identify one's own learning approach
Identify approaches for self-improvement(e.g., continual learning, learning strategies/skills, creating positive beliefs and psychological states,etc)
Display key dispositions (initiative, perseverance, flexibility) in work projects)
Use a range of learning strategies and skills (e.g., goal setting, learning plans, organizing/summarizing information, receiving feedback, etc)
Manage time and resources

3. INTERPERSONAL SKILLS: TEAMWORK & COMMUNICATION

3.1 Teamwork

3.1.1 Form Effective Teams

Identify the components of an effective team
Identify the stages of team formation
Identify team roles and their impact on team performance
Analyze the strengths and weakness of a team

3.1.2 Manage and Participate in Teams

Identify goals and agenda
Apply team ground rules
Apply facilitation and conflict resolution strategies
Display teamwork, including leadership, in a range of team role situations

3.2 Communication

3.2.1 Design appropriate communications strategies

Analyze the communication situation (e.g., in terms of purpose, audience and context (PAC))
Identify key considerations in communicating across cultures and disciplines
Identify communications objectives
Read critically and select relevant content
Identify and choose appropriate communication structure and style
Select appropriate multimedia and graphical communication (e.g. email, voicemail, video conferencing, tables and charts, sketching and drawing)

3.2.2 Demonstrate effective written communication

Write with logical organization and clear language flow
Use concise and precise language
Use correct grammar, spelling and punctuation
Apply appropriate written styles with appropriate formatting conventions to suit PAC

3.2.3 Demonstrate effective oral communication

Design and deliver presentations applying communication design principles
Speak clearly and coherently (e.g., to be understood in a range of communicating situations)
Use appropriate nonverbal communications (e.g., posture, gestures, eye contact)
Demonstrate active and empathetic listening in a range of communication situations (e.g., working in teams, responding to questions, etc)
Ask and answer questions effectively