IMPLEMENTING CDIO IN ELECTRICAL & ELECTRONIC ENGINEERING MODULES: PRACTICAL CHALLENGES AND HOW TO MEET THEM

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ABSTRACT

This paper presents the work of the School of Electrical & Electronic Engineering (SEEE) faculty at Singapore Polytechnic who have been reframing and redesigning their engineering curriculum to make the student learning experience more interesting and aligned to specific CDIO standards for reforming engineering education.

The CDIO framework was implemented in the school in 2008 and required a major review of existing curriculum to identify gaps between existing practices and those suggested by the guiding principles of CDIO. One major outcomes of the review was the creation and introduction of a new project-based module, ‘Introduction to Engineering’, which is aligned with the existing core modules, ‘Principles of Electrical & Electronic Engineering’ and ‘Digital Electronics’. The objective was to provide a more integrated learning experience in which key theoretical concepts and principles, in the two core modules, are integrated and simultaneously applied and immediately in the new module. In the process of this curriculum re-design, 3 key CDIO skills (Personal Skills & Attitudes, Teamwork & Communication) have been systematically integrated into the module program.

In the paper, we present our key findings and significant learning from designing and implementing these first-year introductory courses in our engineering programs at the SEEE. We will show how we have customized CDIO Standards to a polytechnic context and developed integrated, active and experiential learning experiences to help students achieve both a deeper understanding of technical fundamentals and the skills and attitudes required in the wider context of real world engineering

The specific changes relating to curriculum development (e.g. learning outcomes, teaching and assessment) will be identified as well as the challenges faced by staff in attempting to make this curriculum innovation effective and achievable within the inevitable constraints that change typically creates.

Finally, we will present the summarized feedback from students and staffs, obtained through interview, students’ blog and final review, and offer our present frame for future improvement and subsequent CDIO curriculum development.

KEYWORDS
Curriculum, Syllabus, Objectives, Pedagogy, Learning Tasks, Assessment

INTRODUCTION

In reframing and redesigning the engineering curriculum in the School of Electrical & Electronic Engineering (SEEE) to be aligned with specific CDIO standards, a number of generic curriculum development questions must be effectively addressed, these are:

- What present engineering courses are to be reframed and redesigned, and to what extent?
- What specific CDIO skills are to be the primary focus in the curriculum redesign?
- How would the curriculum redesign affect teaching and learning arrangements, as well as the assessment practices?
- How would such changes impact staffing and resource capabilities?
- How might the necessary changes be managed in ways that encouraged stakeholder buy-in and mitigated potential sources and areas of resistance?

In this paper, we will show how the creation of a new project-based module 'Introduction to Engineering' has been used to develop an integrated curriculum with a strong focus on active learning. We specifically focus on how we addressed the essential questions identified above, in order to customize the curriculum to a polytechnic context. Practical examples of the learning outcomes, learning tasks and assessment will be used to illustrate the key decisions taken. Specific challenges faced will be highlighted and the approaches taken to deal with them explained. Finally, based on initial feedback from staff and students, we offer our frame on this curriculum approach and possible future developments in CDIO implementation.

CURRICULUM OUTCOMES

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 (1):

> 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)

It is exactly this question that the CDIO framework seeks to address, and was, in fact, a 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 (2) 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

To provide flexibility, 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.

In further customizing the SP CDIO curriculum outcomes to the specific context of the new project-based module 'Introduction to Engineering', we worked systematically through existing curriculum objectives, with the view to:

- Move the curriculum focus towards more performance-based learning outcomes

- Write specific learning outcomes which systematically infuse selected CDIO skills (in this case, Personal Skills & Attitudes; Interpersonal Skills: Teamwork & Communication) into the content curriculum. (The SP customized CDIO skills are presented in Appendix 1)

In reviewing the existing learning outcomes we noticed a significant number were written in knowledge or comprehension terms (based on Bloom's (3) Taxonomy of Educational Objectives, which is used as the basis for writing learning outcomes in SP). As we wanted to make the module more interesting and real world focused for students, it was readily apparent that we needed to make fairly major changes in the framing of the module's objectives.

In order to achieve this we re-visited the essential question of "what do we really want student to do at the end of this module?' From this we were able to identify a range of key engineering skills, fundamental areas of understanding and critical issues that engineers would encounter in actual engineering environments. It is then a selection and structuring process to ensure that the module has both relevance, structure and one that might excite students to what engineering can be about. Indeed, 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.

In integrating CDIO Skills with the technical content we modelled the infusion approach of Swartz (4). 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 (5) 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 (6), 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 (7) 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.

Having already framed the module towards real world applications, it is then 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. Using this technique in relation to the 'Introduction to Engineering' Module, we were able to identify the specific types of thinking that underpinned competence in the various topic areas. To illustrate, in 'Circuit Design & Production', the following are examples of specific level 4 learning outcomes:

- Compare and contrast the use of a strip board and bread board in circuit design
- Design an appropriate components layout on a strip board
- Analyse integrated circuit and relay datasheets

Table 1 illustrates the revised curriculum outcomes for the IE module.

Table 1

Learning Outcomes
INTRODUCTION TO THE WORLD OF ENGINEERING
Explain the main purpose and goals of the engineering profession.
Analyse the attributes of modern engineers.
Identify the impact of engineering on the environment e.g. economic, social, ecological, etc.
Identify the challenges facing engineering professionals
Identify the basis of values and ethics
Evaluate the impact of values and ethics in engineering decision making
Make sound ethical judgements on issues relating to the professional conduct of engineers

Circuit Design & Production
Explain the purposes and use of electronic circuits
Compare and contrast the use of a strip board and bread board in circuit design
Design an appropriate components layout on a strip board
Assemble components on a strip board to create a circuit
Produce a schematic diagram and artwork using CAD tools
Analyse integrated circuit and relay datasheets
Construct and test a circuit using appropriate tools
Troubleshoot a circuit using appropriate electronic equipment
Integrate circuits using appropriate wires and connectors
Explain the process of fabrication in producing a PCB

Similarly, it was then a fairly straightforward process to infuse other CDIO skills such as communication and teamwork into the module. For example, in the Introduction to Engineering module, as a significant component of the learning activities required students working in groups, this ensured a naturally occurring learning opportunity to include selected ‘Teamwork’ and related ‘Communication’ learning outcomes, such as:

- Identify goals, agenda and team procedures for completing an engineering project
- Identify the stages of team formation and their impact on team performance
- Display teamwork in completing an engineering project
- Design and deliver a presentation to a given audience using appropriate communication strategies
- Speak clearly and coherently in a range of communication situations (e.g., explaining engineering processes, procedures, etc)

ALLIGNING CURRICULUM COMPONENTS

In the CDIO framework, curriculum development follows the principles of ‘component alignment’. This basically means that having derived the curriculum learning outcomes (as documented above), it is then essential to ensure that:

- The instructional strategies and resources used are those most effective and efficient for supporting the learning process to meet these learning outcomes
- The assessment systems (methods and procedures used) are those that provide the most valid and efficient assessment of the learning outcomes.

In this way, the 3 key components of the curriculum (learning outcomes, instructional strategies and assessment) are fully aligned and calibrated.

A major challenge here is to develop learning designs and teaching strategies that are able to provide authentic learning opportunities for student to acquire the necessary skills, and at the appropriate levels. In cases where complex performance (incorporating the integration of concepts, types of thinking, communication skills, etc) was involved, authentic real world tasks would be required to provide both learning and assessment opportunities. As the assessment for this module was 100% in-course assessment through two substantial project components, we were then left with the task of designing projects tasks that ensured learning and assessment opportunities calibrated to the learning outcomes. A project example (including the assessment areas is contained in **Fig 1** below:

Fig 1

Project #2 – Moving Car Transit

NOTES OF GUIDANCE

Objective:

This project requires you to design, build and test electronic circuits necessary to control a range of movements in a model car (e.g., mode forward, reverse and stop, etc).

The project is to be done in groups of 3 to 4 and will be completed by week 15.

Scope:

To meet the project requirements you will need to:

- Form a work team of and organize the necessary activities you will need to do in order to complete the technical requirement specified below. (Note: it is important that your team identifies clear roles and responsibilities, distributing and coordinating various tasks appropriately, and is able to operate as a high performing team).

- Build and test the following circuits:

  1. Light Dependent Sensor Circuit – to detect the station.
  2. Counter & Display Circuit – to display the Station number on the 7 – segment LED display.
  3. Motion Control Circuit – to activate the motor and move the car in forward or reverse direction.
  4. Voltage Regulator Circuit – to provide 5V dc supply.

- Design a Counter Limiting Circuit that is able to integrate the above circuits, enabling the car to move forward to any Station, reverse automatically and stop after hitting an emergency switch (micro switch) in both forward and reverse directions.

- Incorporate additional specific performance and/or aesthetic features which may differentiate your car from the rest (e.g., can do extra movements, perform faster in certain movements, has novel/attractive appearance, etc).

Assessment Components	**Mark weighting in %age**
Plan, Build & Test Circuits 1-4	40%
Counter Limiting Circuit Design	20%
Creativity (e.g., enhanced functionality, aesthetics)	10%
Teamwork (e.g., goal setting, management of team-roles and responsibilities, dealing with conflict/challenges, etc)	10%
Communication (e.g., clarity and cohesiveness of explanation, etc)	20 %
Total	**100%**

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” (8).

IMPLEMENTATION ISSUES

In order to facilitate the curriculum changes outlined above, a number of planning and staff development considerations were addressed. At department level, deputy director and chairmen of course management attended the CDIO overseas conference and shared the experiences and potential benefits with staff. Academic staff underwent a range of training opportunities (e.g., workshops, briefings, etc) to become familiarised with the CDIO Framework, and the specific skills involved in thinking, communication and teamwork. More than forty suitable staff were identified to teach the module which runs across 5 diplomas with total cohort of more than 900 students.

In order to mitigate staff concerns that the implementation of CDIO might not be welcomed by students and subsequently result in low student feedback for staff, a development team was set up to integrate the two core modules in term of scheduling, arranging necessary meetings and other training and administrative support.

As this was the first run of the programme, module coordinators conducted a two day training event for staff to ‘dry-run’ through the module contents, teaching plans, learning outcomes and assessments. 8 labs were extensively renovated with trapezium tables which can be combined to form different layouts for discussion or project work. The Smart board was used for better illustration and presentation, and 6 separate whiteboards on the walls were set up to facilitate group discussions. Technical officers who are competent in project work were selected to man the labs, which were opened for free access even when there were no scheduled lessons.

EVALUATION

In order to evaluate the effectiveness of the module, a number sources of feedback have been sought through the following data collection methods:

- Online blog in which students respond to designated questions posed in relation to specific CDIO activities
- Face-to-face dialogue sessions with class leaders
- Staff dialogue (both ongoing and at end of semester)

The student experience has been particularly interesting and varied. From the dialogue sessions with class leaders, it was apparent that many of the students thought the first project (designing a voltage level detector) helped their understanding of the subject content. However, some felt it was quite difficult and stressful. There may be a need to make certain revisions for projects to allow a more differentiated student experience (e.g., have a minimum level that must be met and additional components for the more competent). This was verified from staff feedback, where the need for more guidance was made apparent.

The second project (moving car transit) while stretching the capability of students, actually resulted in more than 30 groups, each made up of 3-4 students, signing up for the racing competitions across 5 diplomas. Many students displayed creativity and innovation in the designing of the car features.

Overall, students reflected that they had developed their thinking skills and more than 50 % of students expressed that this module makes engineering interesting.

KEY LEARNING & FUTURE DIRECTIONS

> ...the central problem of curriculum study is the gap between our ideals and our attempt to operationalize them. (Stenhouse, 9)

Much planning had gone into the implementation of CDIO, both in terms of curriculum reframing and redesigning, as well as resource provision and staff development activity. The curriculum development activities documented (e.g., ensuring curriculum alignment, appropriate customization of learning outcomes, incorporation of real world activities/projects and robust assessment systems), as well as the necessary staff development support, proved to be invaluable in contributing to the overall success of the implementation. However, despite this extensive planning, there are still many areas that need further improvement and calibration. Some of the more salient areas for improvement include:

- making the introductory project more comfortably achievable so as to sustain student interest.
- balancing students workloads across modules to reduce stress in this area
- a more structured schedule of the learning outcomes to be explicitly taught in the weekly activities.
- greater allocation of time for students to reflect and share learning experiences (e.g., how the learning from projects connects to other engineering related applications).

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Appendix 1

2.4 PERSONAL SKILLS AND ATTITUDES

2.4.1 Apply the thinking process

Use a range of critical thinking skills (e.g., 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 (e.g., Brainstorming, Mindmapping, TRIZ)

Identify contradictory perspectives and underlying assumptions

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)

Evaluate ways to reduce barriers to effective thinking

Identify factors that promote effective thinking (motivation, 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., lifelong learning, creating positive beliefs and psychological states, etc)

Display key dispositions E.G., (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 AND COMMUNICATION

TEAMWORK

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

*A*nalyze the strengths and weakness of a team

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

COMMUNICATIONS

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)

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*

Demonstrate effective oral communication

Design and deliver presentations applying communication design principles (e.g., as *in* 1.1.1 above)

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 a*nswer questions effectively