Rethinking engineering education: the CDIO framework

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OUTLINE

• What is an engineer? What is the professional context of engineering?

• The need for a new approach
  – The CDIO goals and vision
  – What do engineering graduates need to be able to do?
  – How can we do better at educating them?

• Concluding remarks & discussion
WHAT DO ENGINEERS DO?

"Scientists investigate that which already is. Engineers create that which has never been."
- Theodore von Karmann

"What you need to invent, is an imagination and a pile of junk”
- Thomas Edison

DESIRED ATTRIBUTES OF AN ENGINEER
(BOEING, CA 1995)

- A good understanding of engineering science fundamentals
  - Mathematics, Physical and life sciences, Information technology
- A good understanding of design and manufacturing processes
- A multi-disciplinary, systems perspective
- A basic understanding of the context in which engineering is practiced
  - Economics, History, The environment, Customer and societal needs
- Good communication skills - written, oral, graphic, and listening
- A profound understanding of the importance of teamwork.
- Personal skills
  - High ethical standards
  - Ability to think both critically and creatively—indepedently and cooperatively
  - Flexibility
- Curiosity and a desire to learn for life
GOVERNMENTAL EXPECTATIONS

"The engineering profession aims to solve problems of technical nature, concrete and often complex, and associated with the creation, realization and operation of products, systems and services. This ability is the result of a combination of technical knowledge and knowledge of economics and social science, both firmly based in science"

- Commission des titres d’ingénieur, France

(my translation)

THE MAIN GOALS OF ENGINEERING EDUCATION

To educate students who are able to:

- Master a deeper working knowledge of the technical fundamentals
- Lead in the creation and operation of new products, processes, and systems
- Understand the importance and strategic impact of research and technological development on society
EVOLUTION OF ENGINEERING EDUCATION

We are not where we want to be – engineering education needs reform!

CENTRAL QUESTIONS FOR PROFESSIONAL EDUCATION DESIGNERS

- What is the professional role and practical context of the profession(al)? (need)

- What knowledge, skills and attitudes should students possess as they graduate from our programs? (program learning outcomes)

- How can we do better at ensuring that students learn these skills? (curriculum, teaching, learning, workspaces, assessment)

Massachusetts Institute of Technology
THE IMPORTANCE OF THE CONTEXT FOR LEARNING

• The CDIO approach starts in a definition of education context which closely aligned to engineering practice

• Learning in the context of professional practice
  • Communicates the rationale and relevance of what students are learning
  • Interconnects concepts and knowledge that build on each other
  • Increases retention of new knowledge and skills

THE CDIO DEFINITION OF THE CONTEXT OF ENGINEERING PRACTICE

“Engineers Conceive, Design, Implement and Operate complex products and systems in a modern team-based engineering environment”
CONTEXT FOR ENGINEERING:
THE C-D-I-O PROCESS

Lifecycle of a product, process, project, system, software, material

Conceive: customer needs, technology, enterprise strategy, regulations; and conceptual, technical, and business plans

Design: plans, drawings, and algorithms that describe what will be implemented

Implement: transformation of the design into the product, process, or system, including manufacturing, coding, testing and validation

Operate: the implemented product or process delivering the intended value, including maintaining, evolving and retiring the system

FROM CONTEXT TO PROFESSIONAL ROLES

"Engineers Conceive, Design, Implement and Operate complex products and systems in a modern team-based engineering environment"

Research engineer

Design engineer

Req'mnts engineer

Simul'ion engineer

Test engineer

Manuf'cturing manager

Process planner

Maint'enance engineer

Project leader

What roles should we target in our program? How are we doing?
What is the full set of knowledge, skills and attitudes that a student should possess as they graduate from university?

- At what level of proficiency?

- In addition to the traditional engineering disciplinary knowledge

FROM UNDERLYING NEED TO PROGRAM LEARNING OUTCOMES

Educate students who:
- Understand how to conceive-design-implement-operate
- Complex products and systems
- In a modern team-based engineering environment
- And are mature and thoughtful individuals

The CDIO Syllabus - a comprehensive statement of detailed goals for an engineering education
THE CDIO SYLLABUS

• A generalized list of competences that an engineer should possess
  1. Disciplinary Knowledge & Reasoning:
    1.1 Knowledge of underlying sciences
    1.2 Core engineering fundamental knowledge
    1.3 Advanced engineering fundamental knowledge
  2. Personal and Professional Skills
    2.1 Analytical reasoning and problem solving
    2.2 Experimentation and knowledge discovery
    2.3 System thinking
    2.4 Personal skills and attributes
    2.5 Professional skills and attributes

• Program specific (1) and general (2-4)

• Created and validated by alumni, faculty and students

• A "complete" reference model

CDIO Syllabus contains 2-3 more layers of detail

PRIORITIZING LEARNING OUTCOMES – SURVEY OF FACULTY, ALUMNI, INDUSTRY LEADERS

Massachusetts Institute of Technology, Cambridge

REMARKABLE AGREEMENT!
PRIORITIZATION OF CDIO LEARNING OUTCOMES

Queen’s University Belfast

<table>
<thead>
<tr>
<th>Proficiency / Importance</th>
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2.1 Eng. Reasoning and Problem Solving
2.2 Experimenting and Knowledge Discovery
2.3 System Thinking
2.4 Personal Skills
2.5 Professional Skills & Attitudes
3.1 Teamwork and Leadership
3.2 Communications
4.1 External & Societal Context
4.2 Enterprise & Business Context
4.3 Conceiving
4.4 Designing
4.5 Implementing
4.6 Operating

THE CDIO SYLLABUS V 2.0 AS PROGRAM OUTCOMES

<table>
<thead>
<tr>
<th>1.0 Disciplinary Knowledge and Reasoning</th>
<th>1.1 Demonstrate a capacity to use the principles of the underlying sciences</th>
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<tbody>
<tr>
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<tr>
<td></td>
<td>1.1.5 Use the Finite element method to solve partial differential equations</td>
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<td></td>
<td>1.2 Apply the principles of fundamental engineering science</td>
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<td></td>
<td>1.3 Demonstrate a capacity to apply advanced engineering knowledge in the professional areas of engineering</td>
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</tbody>
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<table>
<thead>
<tr>
<th>2.0 Personal and Professional Skills and Attributes</th>
<th>2.1 Analyze and solve engineering problems</th>
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<tbody>
<tr>
<td>2.2 Conduct investigations and experiments about engineering problems</td>
<td></td>
</tr>
<tr>
<td>2.3 Think systemically</td>
<td></td>
</tr>
<tr>
<td>2.4 Demonstrate personal and professional habits that contribute to successful engineering practice</td>
<td></td>
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<tr>
<td>2.5 Demonstrate ethics, equity, and other responsibilities in engineering practice</td>
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### CDIO Syllabus V 2.0 as Program Outcomes (Cont.)

<table>
<thead>
<tr>
<th>3.0</th>
<th>Interpersonal Skills</th>
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<tbody>
<tr>
<td>3.1</td>
<td>Lead and work in groups</td>
</tr>
<tr>
<td>3.2</td>
<td>Communicate effectively</td>
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<tr>
<td>3.3</td>
<td>Communicate effectively in one or more foreign languages.</td>
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<table>
<thead>
<tr>
<th>4.0</th>
<th>CDIO</th>
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<tr>
<td>4.1</td>
<td>Recognize the importance of the social context in the practice of engineering</td>
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<tr>
<td>4.2</td>
<td>Appreciate different enterprise cultures and work successfully in organizations</td>
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<tr>
<td>4.3</td>
<td>Conceive and develop engineering systems</td>
</tr>
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<td>4.4</td>
<td>Design complex engineering systems</td>
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<td>...</td>
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<td>4.5</td>
<td>Implement processes of hardware and software and manage the implementation process</td>
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<td>4.6</td>
<td>Operate complex systems and processes and manage operations</td>
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<td>4.7</td>
<td>Lead engineering endeavors</td>
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<td>4.8</td>
<td>Demonstrate the skills of entrepreneurship</td>
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**How can we do better at assuring that students learn these skills?**

- **Within the available student and faculty time, funding and other resources**
VISION FOR A CDIO-BASED EDUCATION

An education that stresses the fundamentals, set in the context of Conceive – Design – Implement – Operate systems and products:

- A curriculum organised around mutually supporting courses, but with CDIO activities highly interwoven
- Rich with student design-build projects
- Integrating learning of professional skills such as teamwork and communication
- Featuring active and experiential learning
- Constantly improved through quality assurance process with higher aims than accreditation

MORE AND MORE AUTHENTIC DESIGN EXPERIENCES IN THE EDUCATION

**Design-build experiences** are instructional events in which learning occurs through the creation of a product, process, or system

Provide the natural **context** in which to teach design, innovation, implementation skills

Provide a platform for training other CDIO syllabus skills (teamwork, communications etc)
THERE SHOULD BE MULTIPLE DESIGN–BUILD PROJECTS IN THE CURRICULUM

- Intro to Mech Eng
- Joint project in Machine elements & Manuf technology courses
- Machine design
- Mechatronics project course
- Automotive eng project
- Product development project

Creative, "conceptual" design
Design for manufacturing
Redesign Multiple objectives
Creative design incl business aspects Cross-dept teams
Simple prototype Qualitative
More advanced prototype Some simulation Company is customer
Prototype as needed More simulation
Prototype Simulation as needed Company is customer

DEVELOP GENERIC SKILLS THROUGH INTEGRATED LEARNING EXPERIENCES

Integrated learning experiences develop both technical knowledge and “generic” skills (communication, teamwork, ethics, sustainability, etc)

Generic skills are context-dependent and should be learned and assessed in the professional context (Bowden, Barrie, Edström...)

Integrated training of generic skills reinforces understanding of disciplinary content – they will acquire a deeper working knowledge of engineering fundamentals

...communication as a generic skill...
...communication as a contextualized skill...
Communication in engineering means being able to
- Use the technical concepts comfortably
- Discuss a problem of different levels
- Determine what factors are relevant to the situation
- Argue for, or against, conceptual ideas and solutions
- Develop ideas through discussion and collaborative sketching
- Explain technical matters to different audiences
- Show confidence in expressing oneself within the field

The skills are embedded in, and inseparable from, students’ application of technical knowledge.

The same interpretation should be made for teamwork, problem solving, professional ethics, and other engineering skills.

**INTEGRATE THE CURRICULUM**

An integrated curriculum has a systematic assignment of program outcomes to learning activities and features an explicit plan for progressive integration of generic skills.
DEVELOP ACTIVE AND EXPERIENTIAL LEARNING ACTIVITIES

**Active and experiential learning** engages students by setting teaching and learning in contexts that simulate engineering roles and practice.

Reformed mathematics emphasizing simulation of realistic engineering problems.

Working method based on modeling, simulation & analysis, MATLAB programming.

Motivated importance of mathematics and applied mechanics courses.

THE 12 CDIO STANDARDS – GUIDELINES FOR EDUCATION DEVELOPMENT

- **Program focus 1,2,3:**
  - CDIO as Context
  - CDIO Syllabus Outcomes
  - Integrated Curriculum

- **Teaching & Learning 7,8:**
  - Integrated Learning Experiences
  - Active & Experiential Learning

- **Faculty development 9,10:**
  - Enhancement of Faculty CDIO Skills
  - Enhancement of Faculty Teaching Skills

- **Evaluation 11,12:**
  - CDIO Skills Assessment
  - CDIO Program Evaluation
PROGRAM FOCUS

1. The Context
Adoption of the principle that product, process, and system lifecycle development and deployment are the context for engineering education

2. Learning Outcomes
Specific, detailed learning outcomes for personal, interpersonal, and product, process and system building skills, consistent with program goals and validated by program stakeholders

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

“lead and participate in the development of new products, … from stating requirements and formulating the concept, to design, manufacturing, operations and phase-out/shut-down”

4.4.7 Compare and evaluate different product suggestions based on function, environmental impact, production and cost

CONCEIVE-DESIGN-IMPLEMENT-OPERATE LEARNING EXPERIENCES

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

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

6. Engineering Workspaces
Workspaces and laboratories that support and encourage hands-on learning of product, process, and system building, disciplinary knowledge, and social learning
TEACHING AND LEARNING PRACTICES

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

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

FACULTY DEVELOPMENT

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

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

Sustainability in materials courses
Ethics in strength of materials
Presentation skills in microelectronics

Connect with the teaching and learning centers at your universities
Invite guest speakers on teaching topics
Organize coaching by educational professionals or distinguished peers

Hire faculty with industrial experience
Give new hires a year to gain experience before beginning program responsibilities
Create educational programs for current faculty
Provide faculty with leave to work in industry
Recruit senior faculty with significant professional engineering experience
EVALUATION

11. Learning Assessment
Assessment of student learning in personal, interpersonal, and product, process, and system building skills, as well as in disciplinary knowledge

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

CONCLUDING REMARKS

• The CDIO approach provides a reference model for engineering education where professional practice and innovation is focused

• The CDIO approach is codified in the CDIO syllabus and standards. CDIO elements can be used as an integrated set or piecewise, are subject to adaptation to local context etc

• CDIO is an open endeavor – you are all welcome to participate and contribute - 90 universities worldwide are now members of the CDIO Initiative

• To learn more, visit www.cdio.org or read *Rethinking Engineering Education: The CDIO Approach* by Crawley, Malmqvist, Östlund, & Brodeur, 2007
CDIO IS A REFERENCE MODEL, NOT A PRESCRIPTION

Everything has to be *translated-transformed* to fit the context and conditions of each university / program

You are probably doing some CDIO elements already

Take what you want to use, transform it as you wish, give it a new name, assume ownership

CDIO provides a toolbox for working through the process

Thank you for listening!

Any questions or comments?