A CDIO Review:
Engineering Education for the 21st century

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CHALLENGES AND OPPORTUNITIES FOR ENGINEERING EDUCATION

- Remarkable similarity across the world!
- Opportunity: Through use of pedagogical innovation and worldwide collaboration, educate engineers who can develop a better future
• 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
"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
Evolution of Engineering Education

Innovation, Implementation, Collaboration, Practice

Pre-1950s: Practice
1960s: Science & practice
1980s: Science
2000: CDIO

We are not where we want to be – engineering education needs reform!
REFORM OF ENGINEERING EDUCATION IS NEEDED - WITH THREE MAIN GOALS IN MIND

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
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
"Engineers Conceive, Design, Implement and Operate complex products and systems in a modern team-based engineering environment"
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
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
- Program specific (1) and general (2-4)
- Created and validated by alumni, faculty and students
- A "complete" reference model

<table>
<thead>
<tr>
<th>CDIO Syllabus contains 2-3 more layers of detail</th>
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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

3. Interpersonal Skills
   3.1 Multi-disciplinary teamwork
   3.2 Communications
   3.3 Communication in a foreign language

4. CDIO of Complex Systems
   4.1 External and societal context
   4.2 Enterprise and business context
   4.3 Conceiving and engineering systems
   4.4 Designing
   4.5 Implementing
   4.6 Operating
   4.7 Engineer leadership
   4.8 Entrepreneurship
THE CDIO SYLLABUS V2.0 - 3RD LEVEL OF DETAIL (EXCERPT)

1 DISCIPLINARY KNOWLEDGE AND REASONING
   1.1 KNOWLEDGE OF UNDERLYING MATHEMATICS AND SCIENCES
   1.2 CORE ENGINEERING FUNDAMENTAL KNOWLEDGE
   1.3 ADVANCED ENGINEERING FUNDAMENTAL KNOWLEDGE, METHODS AND TOOLS

2 PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES
   2.1 ANALYTICAL REASONING AND PROBLEM SOLVING
      2.1.1 Problem Identification and Formulation
      2.1.2 Modeling
      2.1.3 Estimation and Qualitative Analysis
      2.1.4 Analysis With Uncertainty
      2.1.5 Solution and Recommendation
   2.2 EXPERIMENTATION, INVESTIGATION AND KNOWLEDGE DISCOVERY
      2.2.1 Hypothesis Formulation
      2.2.2 Survey of Print and Electronic Literature
      2.2.3 Experimental Inquiry
      2.2.4 Hypothesis Test and Defense
   2.3 SYSTEM THINKING
      2.3.1 Thinking Holistically
      2.3.2 Emergence and Interactions in Systems
      2.3.3 Prioritization and Focus
      2.3.4 Trade-offs, Judgment and Balance in Resolution
   2.4 ATTITUDES, THOUGHT AND LEARNING
      2.4.1 Initiative and the Willingness to Make Decisions in the Face of Uncertainty
      2.4.2 Perseverance, Urgency and Will to Deliver, Resourcefulness and Flexibility
      2.4.3 Creative Thinking
      2.4.4 Critical Thinking
      2.4.5 Self-awareness, Meta-cognition and Knowledge Integration
      2.4.6 Lifelong Learning and Educating
      2.4.7 Time and Resource Management
   2.5 ETHICS, EQUITY AND OTHER RESPONSIBILITIES
      2.5.1 Ethics, Integrity and Social Responsibility
      2.5.2 Professional Behavior
      2.5.3 Proactive Vision and Intention in Life
      2.5.4 Staying Current on the World of Engineering
      2.5.5 Equity and Diversity
      2.5.6 Trust and Loyalty

3 INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION
   3.1 TEAMWORK
      3.1.1 Forming Effective Teams
      3.1.2 Team Operation
      3.1.3 Team Growth and Evolution
      3.1.4 Team Leadership
      3.1.5 Technical and Multidisciplinary Teaming
   3.2 COMMUNICATIONS
      3.2.1 Communications Strategy
      3.2.2 Communications Structure
      3.2.3 Written Communication
      3.2.4 Electronic/Multimedia Communication
      3.2.5 Graphical Communication
      3.2.6 Oral Presentation
      3.2.7 Inquiry, Listening and Dialog
      3.2.8 Negotiation, Compromise and Conflict Resolution
      3.2.9 Advocacy
      3.2.10 Establishing Diverse Connections and Networking
   3.3 COMMUNICATIONS IN FOREIGN LANGUAGES
      3.3.1 Communications in English
      3.3.2 Communications in Languages of Regional Nations
      3.3.3 Communications in Other Languages
Sample: 6 groups surveyed: 1st- and 4th-year students, alumni 25 years old, alumni 35 years old, faculty, leaders of industry

Question: For each attribute, please indicate which of the five levels of proficiency you desire in a graduating engineering student:

Scale:

1 To have experienced or been exposed to
2 To be able to participate in and contribute to
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 in
Analysis is rated highest but almost as high proficiency is needed in design, communication and teamwork
• The CDIO syllabus has been compared national accreditations in many countries.

• Same pattern:
  – The CDIO Syllabus states outcomes for engineering education that reflect a broader view of the engineering profession.
  – Its greater levels of detail facilitate program and course development.
  – A program whose design is based on the CDIO Syllabus will also satisfy its national requirements for specified program outcomes.
• 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—indepenedently and cooperatively
  – Flexibility
• Curiosity and a desire to learn for life
How can we do better at assuring that students learn these skills?

– *Within the available student and faculty time, funding and other resources*
An education that stresses the fundamentals, set in the context of Conceiving – Designing – Implementing – Operating 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
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
- Creative, "conceptual" design
- Simple prototype Qualitative

**Year 2**
- Machine design
- Design for manufacturing
- More advanced prototype
- Some simulation
- Company is customer

**Year 3**
- Redesign
- Multiple objectives
- Prototype as needed
- More simulation

**Year 4**
- Mechatronics project course
- Automotive eng project
- Product development project
- Creative design incl business aspects
- Cross-dept teams
- Prototype
- Simulation as needed
- Company is customer
DESIGN-BUILD-TEST PROJECTS ADDRESS SUSTAINABLE INNOVATION

- 4th year Product development project course, interdisciplinary student teams

- Design-build and business development

- Collaboration with start-ups and established firms

Solar tracker actuator (SKF)

Wave energy (Vigor Wave)

Ultralight electric vehicle (CleanMotion)
STUDENT WORKSPACES FOR CDIO
EXAMPLE:
MIT AERO-ASTRO DEPARTMENT

Conceive

Design

Implement

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

Knowledge & skills give each other meaning!

Source: Kristina Edström
DISCIPLINE-LED PROBLEM/ PRACTICE-BASED LEARNING

Discipline-led learning

• Well-structured knowledge base (“content”)
• What is known and what is not
• Evidence/theory, Model/reality
• Methods to further the knowledge frontier

CONNECTING WITH GENERIC SKILLS

➢ Working understanding = capability to apply, functioning knowledge
➢ Seeing the knowledge through the lens of problems, interconnecting the disciplines
➢ Integrating skills, e.g. communication and collaboration

Problem/practice-led learning

• Integration and application, synthesis
• Open-ended problems, ambiguity, conflicting interests, trade-offs
• Working under conditions of specific contexts
• Professional skills (work processes)
• “Creating that which has never been”
• Knowledge building of the practice

CONNECTING WITH DISCIPLINARY KNOWLEDGE

➢ Drawing on the disciplinary knowledge
➢ Reinforcing disciplinary understanding
➢ Creating a motivational context
Communication in lightweight design 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.

It is about educating engineers who can actually communicate about engineering!

The same interpretation should be made for teamwork, problem solving, professional ethics, and other engineering skills.
An **integrated curriculum** has a systematic assignment of program outcomes to learning activities and features an explicit plan for progressive integration of generic skills.

**Planned learning sequence -- Vehicle Engineering -- KTH**

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<thead>
<tr>
<th>CDIO Syllabus</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
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<tbody>
<tr>
<td>3.2.3 Written communication</td>
<td>Introductory course</td>
<td>Mech I</td>
<td>Mech II</td>
</tr>
<tr>
<td></td>
<td>Math I</td>
<td>Mech II</td>
<td>Thermo-dynamics</td>
</tr>
<tr>
<td></td>
<td>Physics</td>
<td>Solid Mechanics</td>
<td>Math III</td>
</tr>
<tr>
<td></td>
<td>Numerical Methods</td>
<td>Product development</td>
<td>Electrical Eng.</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Statistics</td>
</tr>
<tr>
<td>3.3 Communication in English</td>
<td>Math I</td>
<td>Math II</td>
<td>Control Theory</td>
</tr>
<tr>
<td></td>
<td>Mechanical Engineering</td>
<td>Mech II</td>
<td>FEM in Engineering</td>
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<tr>
<td></td>
<td>Thermo-dynamics</td>
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<td></td>
<td>Fluid Mechanics</td>
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<td>Control Theory</td>
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<td></td>
<td>Optimization</td>
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INTEGRATED LEADERSHIP TRAINING

The Gordon-MIT Engineering Leadership Program

Gordon Engineering Leader Program

- Freshman Year
  - Fall: UPOP
  - Spring: UPOP Internship

- Sophomore Year
  - Fall: Engineering Innovation & Design
  - Spring: Engineering Leadership Lab

- Summer
  - Engineering Leadership Lab
  - Realistic-Scale Project
  - Personal Leadership Development Plan

- GEL Year 1 (The Many)
  - Fall: Gordon Internship Plus
  - Spring: People & Organizations

- GEL Year 2 (The Few)
  - Fall: Project Engineering
  - Spring: 2nd Realistic-Scale Project
  - Personal Leadership Development Plan

- Industry & Alum Mentoring
  - Apply to GEL Year 1
  - Apply to GEL Year 2
  - Receive One Year Certificate of Completion

Approx. 300 Students

Approx. 100 Students

Approx. 30 Students

All MIT Students

- Freshman Project-Based Subjects
- Teamwork Module
- Leadership Module
- Gordon Leadership Subjects
- Project Engineering Module
- Design/Build Projects
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.
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.
CONCLUDING REMARKS – WHAT IS CDIO

• An **idea** of what engineering students should learn: “Engineers who can engineer”

• A **methodology** for engineering education reform: The CDIO Syllabus and the 12 CDIO Standards

• A **community**: The CDIO Initiative with 107 universities as members

• To learn more, visit [www.cdio.org](http://www.cdio.org) or read *Rethinking Engineering Education: The CDIO Approach* by Crawley, Malmqvist, Östlund & Brodeur, 2007
Thank you for listening!

Any questions or comments?