CDIO – Engineering Education for the 21st Century

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Chalmers University of Technology
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OUTLINE

- What is CDIO?
- Case: CDIO in Chalmers’ mechanical engineering programme
- CDIO development directions
WHAT IS CDIO?

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

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

• A **community**: The CDIO Initiative with 140+ universities as members
WHAT SHOULD ENGINEERING STUDENTS LEARN?

HOW SHOULD THEY LEARN IT?
"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
"Engineers Conceive, Design, Implement and Operate complex products and systems in a modern team-based engineering environment"
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

Duke University
THE CDIO SYLLABUS 2.0

- 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

1. Disciplinary Knowledge & 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
   2.1 Analytical reasoning and problem solving
   2.2 Experimentation, investigation and knowledge discovery
   2.3 System thinking
   2.4 Attitudes, thought and learning
   2.5 Ethics, equity and other responsibilities

3. Interpersonal Skills
   3.1 Teamwork
   3.2 Communications
   3.3 Communication in a foreign language

4. CDIO of Complex Systems
   4.1 External, societal and environmental context
   4.2 Enterprise and business context
   4.3 Conceiving, systems engineering and management
   4.4 Designing
   4.5 Implementing
   4.6 Operating
   4.7 Leadership
   4.8 Entrepreneurship

CDIO Syllabus contains 2-3 more layers of detail
An education that stresses the fundamentals, set in the context of **Conceiving – Designing – Implementing – Operating** systems and products:

- Clear, detailed programme learning outcomes that express a holistic view of engineering
- A curriculum organised around mutually supporting courses, 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
- Taught by teachers with scientific, engineering and pedagogic competence
- Constantly improved through quality assurance process with higher aims than accreditation
REQUIREMENT FOR REFORM

**Retask current assets and resources in:**

- Curriculum
- Teaching and learning methods
- Design-implement experiences and engineering workspaces
- Learning assessment methods
- Faculty competence
- Program evaluation

A systematic approach is needed to address these issues!
THE CDIO EDUCATION DEVELOPMENT METHODOLOGY
CDIO DEVELOPMENT METHODOLOGY

- **CDIO syllabus** – WHAT

- **CDIO standards** – HOW

- **CDIO curriculum design process** – from WHAT to HOW

- **CDIO standards self-evaluation** – HOW WELL
THE 12 CDIO STANDARDS – THE GUIDELINES FOR CDIO DEVELOPMENT

- **Context & goals 1,2**
  - CDIO as Context
  - CDIO Syllabus Outcomes

- **CDIO curriculum & space 3,4,5,6**
  - Integrated Curriculum
  - Introduction to Engineering
  - Design-Build Experiences
  - CDIO Workspaces

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

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

- **Evaluation 11,12**
  - CDIO Skills Assessment
  - CDIO Program Evaluation
CASE:

MECHANICAL ENGINEERING AT CHALMERS UNIVERSITY OF TECHNOLOGY, SWEDEN
| Identify needs & opportunities for change | **Strengths**  
• Project-based courses  
• Design courses  

**Weaknesses**  
• No design-build-test projects, lack of authenticity  
• Employer requested better communication skills, project leadership & initiative  
• Poor links between maths and engineering subjects |
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Establish vision &amp; strategy</td>
<td>CDIO was selected as basis for a program vision &amp; strategy</td>
</tr>
<tr>
<td>Identify early successes</td>
<td>4\textsuperscript{th} year design-build-test competition-based projects were focused (Formula Student, Autonomous vehicles)</td>
</tr>
<tr>
<td>Set up system for measuring the change</td>
<td>Self-assessment vs CDIO standards</td>
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</table>
Design-implement experiences are instructional events in which learning occurs through the creation of a product, process, or system.

- Train authentic engineering and decision-making

- Provide the natural context in which to teach many CDIO syllabus skills (teamwork, communications, ethics)
DESIGN-BUILD-TEST PROJECT EXAMPLE

Chalmers
Eco-Marathon Vera
A PLANNED LEARNING SEQUENCE FOR DESIGN SKILLS

Year 1
- Intro to Mech Eng
  - Creative, "conceptual" design
  - Simple prototype
    - Qualitative

Year 2
- Joint project in Machine elements & Manuf technology courses
  - Design for manufacturing
    - More advanced prototype
      - Some simulation
        - Company is customer

Year 3
- Machine design
  - Redesign
    - Multiple objectives
      - Prototype as needed
        - More simulation
          - Simulation as needed
            - Company is customer

Year 4
- Mechatronics project course
- Automotive eng project
- Product development project
  - Creative design incl business aspects
    - Cross-dept teams
THE PROTOTYPING LABORATORY

- 450 m² facility where students can build prototypes

- Metal machining, woodworking, rapid prototyping, waterjet welding, electronics, composites …

- Used in courses and projects from year 1 to master thesis projects
Integrated learning experiences develop both technical knowledge and “generic” skills (communication, teamwork, ethics, sustainability, etc).

Source: Kristina Edström
# INTEGRATED CURRICULUM YEAR 1-3

## Year 1

<table>
<thead>
<tr>
<th>Course</th>
<th>ECTS</th>
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</thead>
<tbody>
<tr>
<td>Intro Mathematics</td>
<td>7.5</td>
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<tr>
<td>Single-variable Calculus</td>
<td>7.5</td>
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<tr>
<td>Linear Algebra</td>
<td>7.5</td>
</tr>
<tr>
<td>Several-variable Calculus</td>
<td>7.5</td>
</tr>
<tr>
<td>Programming in Matlab</td>
<td>4.5</td>
</tr>
<tr>
<td>Intro to Mechanical Eng</td>
<td>7.5</td>
</tr>
<tr>
<td>Mechanics and Solid Mechanics I</td>
<td>7.5</td>
</tr>
<tr>
<td>Mechanics and Solid Mechanics I II</td>
<td>7.5</td>
</tr>
<tr>
<td>Intro to Mechanical Eng</td>
<td>7.5</td>
</tr>
<tr>
<td>Machine Elements</td>
<td>7.5</td>
</tr>
<tr>
<td>Materials</td>
<td>7.5</td>
</tr>
<tr>
<td>Machine Elements</td>
<td>7.5</td>
</tr>
<tr>
<td>Integrated Design and Manufacturing Project</td>
<td>7.5</td>
</tr>
<tr>
<td>Materials and Manufacturing Technology</td>
<td>7.5</td>
</tr>
<tr>
<td>Sustainable product development</td>
<td>4.5</td>
</tr>
<tr>
<td>Thermodynamics</td>
<td>7.5</td>
</tr>
<tr>
<td>Industrial Economics</td>
<td>4</td>
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</tbody>
</table>

## Year 2

<table>
<thead>
<tr>
<th>Course</th>
<th>ECTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanics and Solid Mechanics I II</td>
<td>7.5</td>
</tr>
<tr>
<td>Machine Elements</td>
<td>7.5</td>
</tr>
<tr>
<td>Integrated Design and Manufacturing Project</td>
<td>7.5</td>
</tr>
<tr>
<td>Materials</td>
<td>7.5</td>
</tr>
<tr>
<td>Materials and Manufacturing Technology</td>
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</tr>
<tr>
<td>Sustainable product development</td>
<td>4.5</td>
</tr>
<tr>
<td>Thermodynamics</td>
<td>7.5</td>
</tr>
<tr>
<td>Industrial Economics</td>
<td>4</td>
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</tbody>
</table>

## Year 3

<table>
<thead>
<tr>
<th>Course</th>
<th>ECTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechatronics</td>
<td>7.5</td>
</tr>
<tr>
<td>Control Engineering</td>
<td>7.5</td>
</tr>
<tr>
<td>Bachelor Thesis Project</td>
<td>15</td>
</tr>
<tr>
<td>Fluid Mechanics</td>
<td>7.5</td>
</tr>
<tr>
<td>Elective I</td>
<td>7.5</td>
</tr>
<tr>
<td>Elective II</td>
<td>7.5</td>
</tr>
<tr>
<td>Mathematical Statistics</td>
<td>7.5</td>
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## Common
computation labs in mathematics, programming & engineering science

- Communications
- Teamwork
- Sustainability
- Ethics

## Integrative project in design & manufacturing
• Motivate importance of mathematics and applied mechanics courses
• Realistic engineering problems

• Working method based on modelling, simulation & analysis
• MATLAB programming
• Visualization of mechanical behaviour

Year 1 lab example
Analys av plan elastiska skiva med fyra hål

Beräkna spänningskonzentrationsfaktorn. Avgör om spänningshöjningarna vid hålen samverkar. Symmetrier skall utnyttjas.
# A CULTURE OF CHANGE

<table>
<thead>
<tr>
<th>Pre CDIO</th>
<th>CDIO planning</th>
<th>CDIO basic design &amp; piloting</th>
<th>CDIO implementation</th>
<th>CDIO +</th>
</tr>
</thead>
</table>
| M2000 reform  
- Project courses  
- More design  
- Early eng experiences  
- Master-like profiles  
- No design-build-test | Set project goals  
Concretize CDIO concept  
Bench-marking  
Design-build-test pilots | Prototyping lab  
Multiple design-build-test projects  
Integrated learning  
3+2 education structure adapted | Mathematics  
Sustainability  
Bachelor project  
English on master level  
HSV Excellence center | Virtual learning environment for math stat  
Integrated sustainability Material science courses with product focus |
|  |  |  |  |  |

- Set new goals  
- Visiting committee
CURRENT FOCUS

• Entrepreneurship for the few and for the many
• New technologies & materials
• Preparing for global collaboration and competition
• Ethics
• Blended learning
• Challenge-based learning experiences
• Composites fabrication
• ...
• …
CURRENT CDIO DEVELOPMENTS
Library for on-line learning of design methods developed for use across multiple design courses (Chalmers)

<table>
<thead>
<tr>
<th>Conceive</th>
<th>PEST analysis</th>
<th>SWOT analysis</th>
<th>Customer needs elicitation</th>
<th>Requirements specification</th>
<th>Benchmarking</th>
<th>Questionnaire design</th>
<th>Market identification and selection</th>
<th>…</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>Function structure</td>
<td>Morphological matrix</td>
<td>Pugh matrix</td>
<td>Kesselring matrix</td>
<td>Matlab optimization</td>
<td>STL model validation</td>
<td>FMEA</td>
<td>…</td>
</tr>
<tr>
<td>Implement</td>
<td>Design of experiments</td>
<td>Prototyping lab machine tutorials (multiple)</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
</tr>
<tr>
<td>Operate</td>
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<td>…</td>
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On-line learning of CDIO for faculty as well as student (Singapore Polytechnic)
A challenge-based learning experience is a learning experience where the learning takes places through the identification, analysis and design of a solution to a sociotechnical problem.

A challenge-based learning experience is typically multidisciplinary, takes place in an international context and, aims to find a collaboratively developed solution, which is environmentally, socially and economically sustainable.
EXAMPLE: CHALMERS C-LABS

- Sustainability-related challenges

- Master-level course + thesis open to students from all of Chalmers programs

- Regional problem scope and involvement

- Lab outside of Chalmers – neutral ground
THE COURSE DESIGN

Theme setting
- Dialogues with stakeholders
- Visioning & backcasting
- Problem identification & formulation
- Self-leadership training
- Entrepreneurship

Conception – Design – Implementation
Set of mutually supporting projects

Theme: Urban transportation in Gothenburg region
- Biodiesel fuels in Sweden
- Redefinition of transport sharing system
- ...
- ...

Problem formulation phase
Jan-Feb

Conceive, design & implementation phase
Mar-June
TO SUMMARIZE:

CDIO aims 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

• To learn more, visit www.cdio.org or read *Rethinking Engineering Education: The CDIO Approach, 2nd ed* by Crawley, Malmqvist, Östlund, Brodeur & Edström, 2014
Thank you for listening!

Any questions or comments?