# CDIO – Engineering Education for the 21$^{st}$ Century

**Professor Johan Malmqvist**
Chalmers University of Technology
Gothenburg, Sweden

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# OUTLINE

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

# WHAT IS CDIO?

- **An <u>idea</u> of what engineering students should learn and how: To become "Engineers who can engineer"**

- **A <u>methodology</u> for engineering education reform: The CDIO Syllabus and the 12 CDIO Standards**

- **A <u>community</u>: The CDIO Initiative with 140+ universities as members**

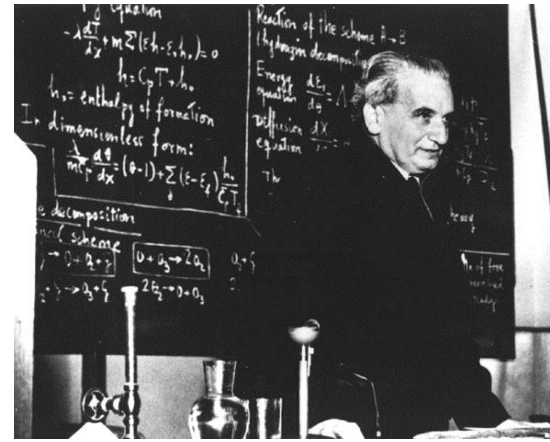
# THE IDEA IN CDIO

***WHAT* SHOULD ENGINEERING STUDENTS LEARN?**

***HOW* SHOULD THEY LEARN IT?**

# THE PROFESSIONAL ROLE OF ENGINEERS

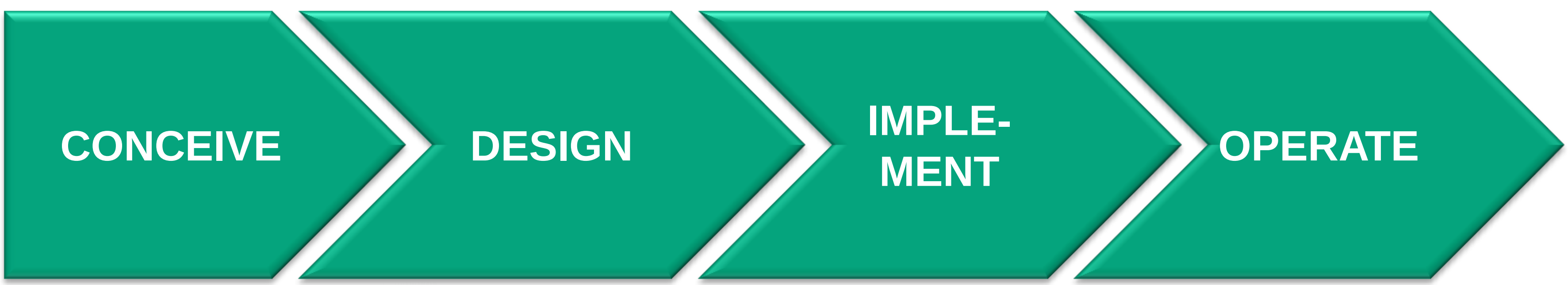
**”Scientists investigate that which already is. Engineers <u>create</u> that which has never been.**
**- Theodore von Karmann**



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

# THE CDIO DEFINITION

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



# THE C-D-I-O PROCESS

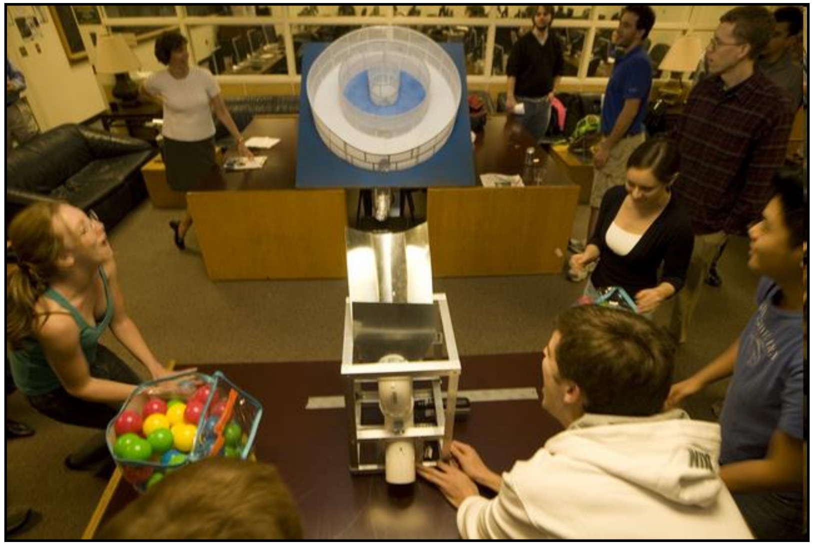
## Lifecycle of a product, process, project, system, software, material

**C**onceive: customer needs, technology, enterprise strategy, regulations; and conceptual, technical, and business plans

**D**esign: plans, drawings, and algorithms that describe what will be implemented

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

**O**perate: 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

# VISION FOR A CDIO-BASED EDUCATION

**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**

# NEED 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***

1 **Disciplinary Knowledge & Reasoning:**
1.1 Knowledge of underlying mathematics and sciences
1.2 Core engineering fundamental knowledge
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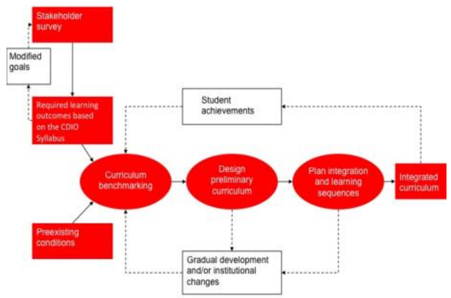
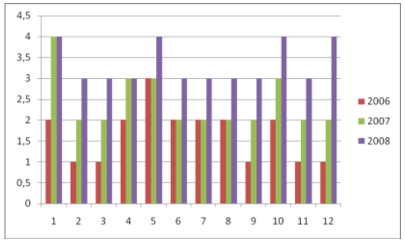
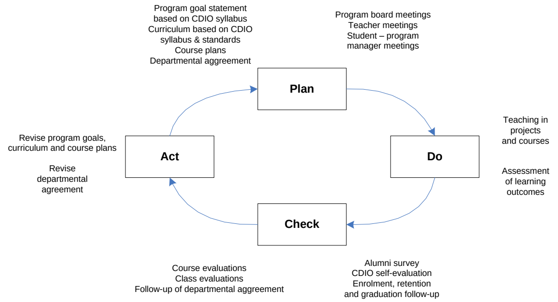
**1. The Context**
Adoption of the principle that product. Process, and system lifecycle development and deployment are the context for engineering education
**2. Learning Outcomes**
Specific, detailed learning outcomes for personal, interpersonal, and product,.process and system building skills, consistent 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
**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

**7. Integrated Learning Experiences**
Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal, interpersonal, and produc, process,t and system building skills
**8. Active Learning**
Teaching and learning based on active experiential learning methods
**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
**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

THE CDIO CURRICULUM DESIGN PROCESS



# THE 12 CDIO STANDARDS – THE GUIDELINES FOR CDIO DEVELOPMENT

cdio

**Context & golals 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*

# PLANNING THE CHANGE AT CHALMERS

| | |
|---|---|
| **Identify needs & opportunities for change** | ***Strengths*** + More<br>• Project-based courses<br>• Design courses<br><br>***Weaknesses***<br>• No design-build-test projects, lack of authenticity<br>• Employer requested better communication skills, project leadership & initiative + More<br>• Poor links between maths and engineering subjects |
| **Establish vision & strategy** | CDIO was selected as basis for a program vision & strategy |
| **Identify early successes** | 4th year design-build-test competition-based projects were focused (Formula Student, Autonomous vehicles) |
| **Set up system for measuring the change** | Self-assessment vs CDIO standards |

# DESIGN-IMPLEMENT EXPERIENCES

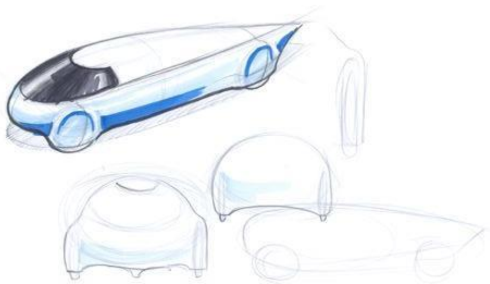
**Design-implement experiences** are instructional events in which learning occurs through the creation of a product, process, or system

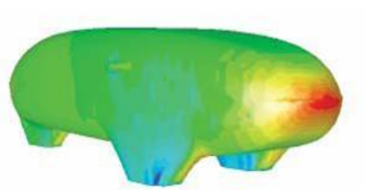
- **Train authentic engineering and decision-making**

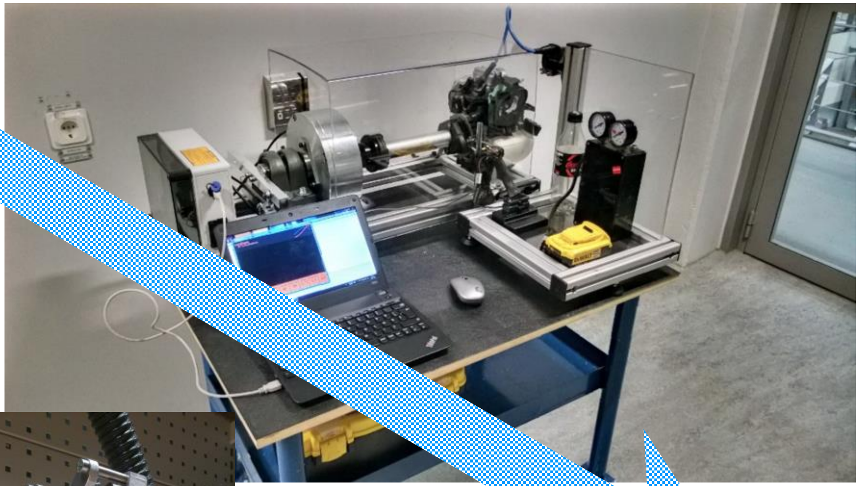
- **Provide the natural context in which to teach many CDIO syllabus skills (teamwork, communications, ethics)**

# DESIGN-BUILD-TEST PROJECT EXAMPLE

*Chalmers*
*Eco-Marathon Vera*





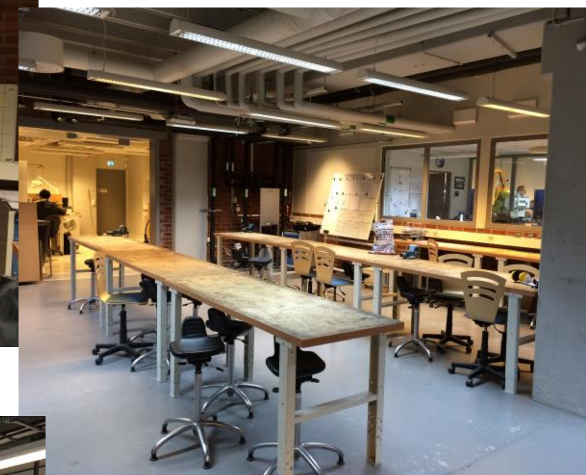


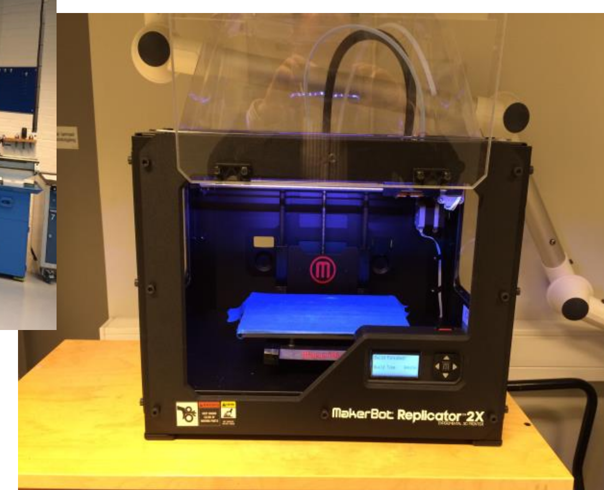

# A PLANNED LEARNING SEQUENCE FOR DESIGN SKILLS

| Year 1 | Year 2 | Year 3 | Year 4 |
|---|---|---|---|
| Intro to Mech Eng | Joint project in Machine elements & Manuf technology courses | Machine design | Mechatronics project course<br>Automotive eng project<br>Product development project |
| Creative, ”conceptual” design | Design for manufacturing | Redesign<br>Multiple objectives | Creative design incl business aspects<br>Cross-dept teams |
| Simple prototype<br>Qualitative | More advanced prototype<br>Some simulation<br>Company is customer | Prototype as needed<br>More simulation | Prototype<br>Simulation as needed<br>Company is customer |

# THE PROTOTYPING LABORATORY

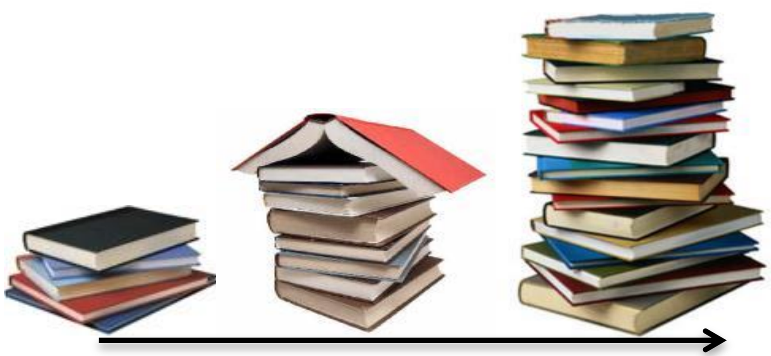
- 450 m2 facility where students can build prototypes
- Metal machining, woodworking, rapid prototyping, waterjet welding, electronics, composites …
- Used in courses and projects from year 1 to master thesis projects



# INTEGRATED LEARNING EXPERIENCES

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



*Acquisition of technical knowledge*

*Development of generic skills*

*Source: Kristina Edström*

# INTEGRATED CURRICULUM YEAR 1-3

**Year 1**

| | | | |
|---|---|---|---|
| Intro Mathematics 7.5 ECTS | Single-variable Calculus 7.5 ECTS | Linear Algebra 7.5 ECTS | Several-variable Calculus 7.5 ECTS |
| Programming in Matlab 4.5 ECTS | CAD M 4 hp | Mechanics and Solid Mechanics I 7.5 ECTS | Mechanics and Solid Mechanics I I 7.5 ECTS |
| Intro to Mechanical Eng 7.5 ECTS | | | |

**Year 2**

| | | | |
|---|---|---|---|
| Mechanics and Solid Mechanics I II 7.5 ECTS | Machine Elements 7.5 ECTS | Integrated Design and Manufacturing Project 7.5 ECTS | |
| Materials 7.5 ECTS | Materials and Manufacturing Technology 7.5 ECTS | Sustainable product development 4.5 ECTS | Industrial Production & Org 6 ECTS |
| | | Thermodynamics 7.5 ECTS | Industrial Economics 4 ECTS |

**Year 3**

| | | | |
|---|---|---|---|
| Mechatronics 7.5 ECTS | Control Engineering 7.5 ECTS | Bachelor Thesis Project 15 ECTS | |
| Fluid Mechanics7.5 ECTS | Elective I 7.5 ECTS | Elective II 7.5 ECTS | Mathematical Statistics 7.5 ECTS |

**Common computation labs in mathematics, programming & engineering science**

**Communications**

**Teamwork**

**Sustainability**

**Ethics**

**Integrative project in design & manufacturing**

# REFORMED MATHEMATICS EMPHASIZING SIMULATIONS

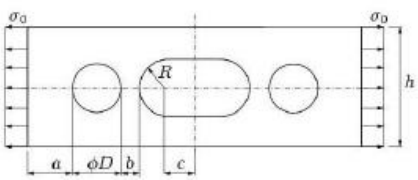
- **Motivate importance of mathematics and applied mechanics courses**
- **Realistic engineering problems**

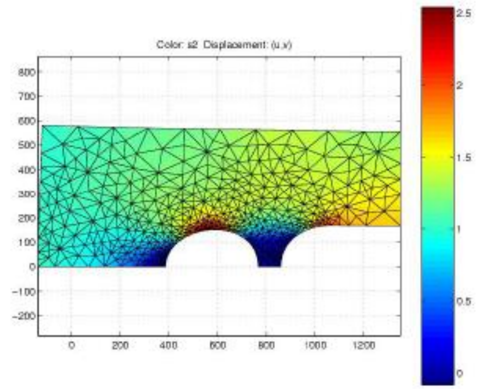
- **Working method based on modelling, simulation & analysis**
- **MATLAB programming**
- **Visualization of mechanical behaviour**

**Year 1 lab example**

**Analys av plan elastiska skiva med fyra hål**

Beräkna spänningskoncentrationsfaktorn. Avgör om spänningshöjningarna vid hålen samverkar. Symmetrier skall utnyttjas.



# A CULTURE OF CHANGE

| Pre CDIO | CDIO planning | CDIO basic design & piloting | CDIO implementation | CDIO + |
|---|---|---|---|---|
| -2000 | 2000-2001 | 2001-2004 | 2004-2008 | 2009-2013 |
| M2000 reform<br>• Project courses<br>• More design<br>• Early eng experiences<br>• Master-like profiles<br><br>• No design-build-test | • Set project goals<br>• Concretize CDIO concept<br>• Bench-marking<br>• Design-build-test pilots | • Prototyping lab<br>• Multiple design-build-test projects<br>• Integrated learning<br>• 3+2 education structure adapted | • Mathematics<br>• Sustainability<br>• Bachelor project<br>• English on master level<br><br>• HSV Excellence center | • Virtual learning environment for math stat<br>• Integrated sustainability Material science courses with product focus<br><br>• Set new goals<br>• 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*

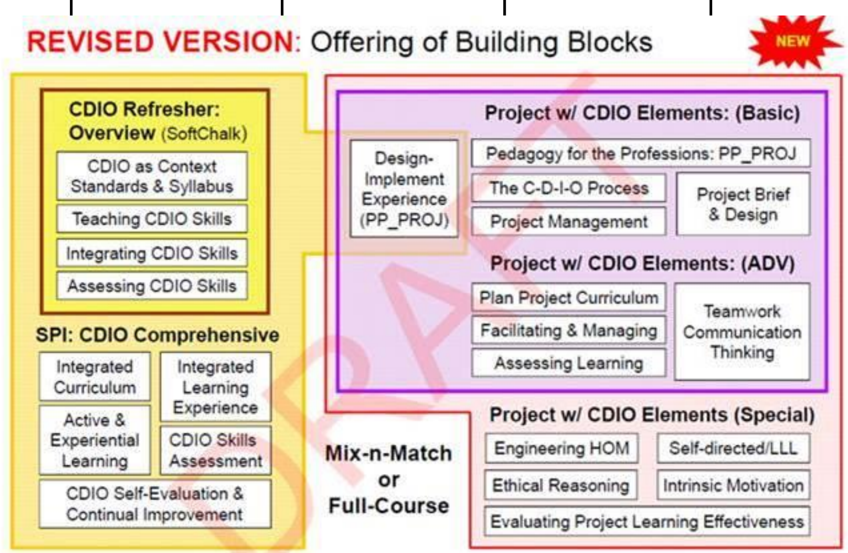
# DIGITAL LEARNING OF CDIO SKILLS

## Library for on-line learning of design methods developed for use across multiple design courses (Chalmers)

***Under development***

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Conceive** | PEST analysis | SWOT analysis | Customer needs elicitation | Requirements specification | Benchmarking | Questionnaire design | Market identification and selection | … |
| **Design** | Function structure | Morpho-logical matrix | Pugh matrix | Kesselring matrix | Matlab optimization | STL model validation | FMEA | … |
| **Implement** | Design of experi-ments | Prototyping lab machine tutorials (multiple) | | … | | | | |
| **Operate** | … | | | | | | | |

## On-line learning of CDIO for faculty as well as student (Singapore Polytechnic)



# CHALLENGE-BASED LEARNING EXPERIENCES

**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

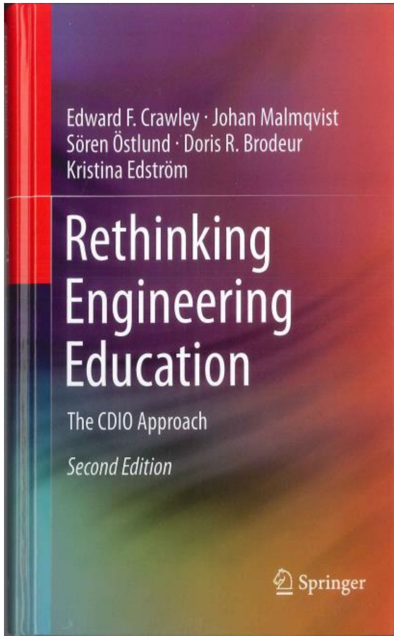
Conceive, design & implementation phase

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](http://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?**