CONCEIVE DESIGN IMPLEMENT OPERATE

The CDIO approach
for engineering education development

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Who is Kristina Edström?

- **Engineer & Educational developer**
  - M. Sc. in Engineering, Chalmers
  - Associate Professor in *Engineering Education Development* at KTH Royal Institute of Technology, Stockholm, Sweden
  - 2012-2013 Director of Educational Development at Skolkovo Institute of Science and Technology, Moscow
- **Strategic educational development, national and international**
  - CDIO Initiative for reform of engineering education since 2001
  - Member of the CDIO Council, 2005-2013
  - SEFI Administrative Council, 2010-2013
  - Contributor to Crawley et al (2007, 2nd ed. 2014) Rethinking Engineering Education: The CDIO Approach, Springer.
- **Faculty development**
  - So far 700 participants have taken the 7.5 ECTS course *Teaching and Learning in Higher Education,* customized for KTH faculty

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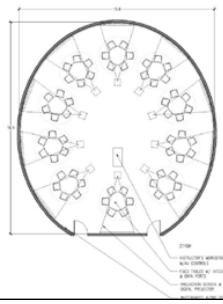

"If you want to learn about a system, try to change it"

(after Le Chatelier's principle)

What is CDIO?

1. An idea of what engineering students should learn and why

"Engineers who can engineer"

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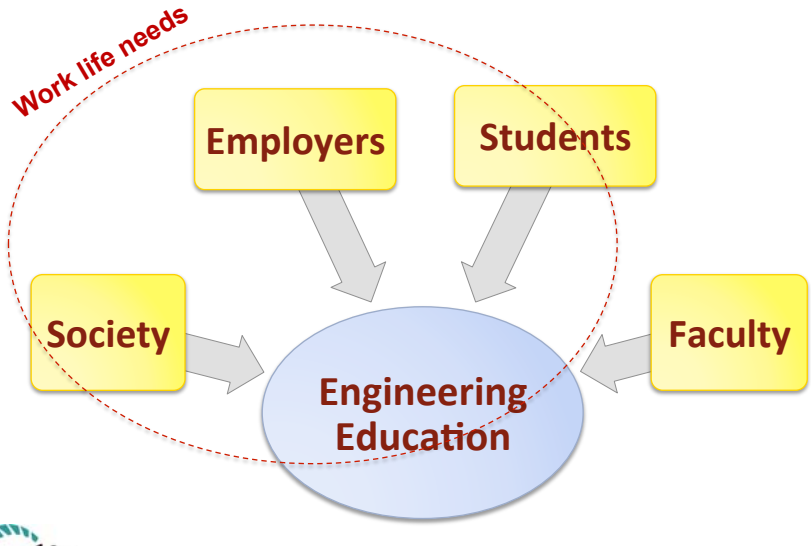
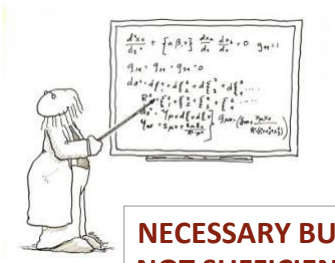
Stakeholder perspectives



Work life skills

Disciplinary theory applied to "Problem-solving"



NECESSARY BUT NOT SUFFICIENT

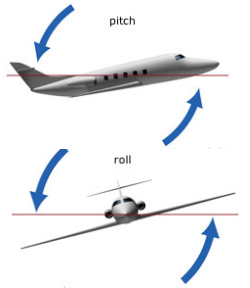
Theory and judgement applied to real problems

Real problems

- Cross disciplinary boundaries
- Sit in contexts with societal and business aspects
- Complex, ill-defined and contain tensions
- Need interpretations and estimations ('one right answer' are exceptions)
- Require systems view

Work life skills

Technology in itself



NECESSARY BUT NOT SUFFICIENT

Engineering as process:

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

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Work life skills

Individual approach

NECESSARY BUT NOT SUFFICIENT

Communicative and collaborative approach

- Crucial for all engineering work processes
- Much more than working in project teams with well-defined tasks
- Engineering is a social activity involving customers, suppliers, colleagues, citizens, authorities, competitors
- Networking within and across organizational boundaries, over time, in a globalised world

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CDIO Standard 1: The context

Educating for the context of engineering

Education set in
Engineering science

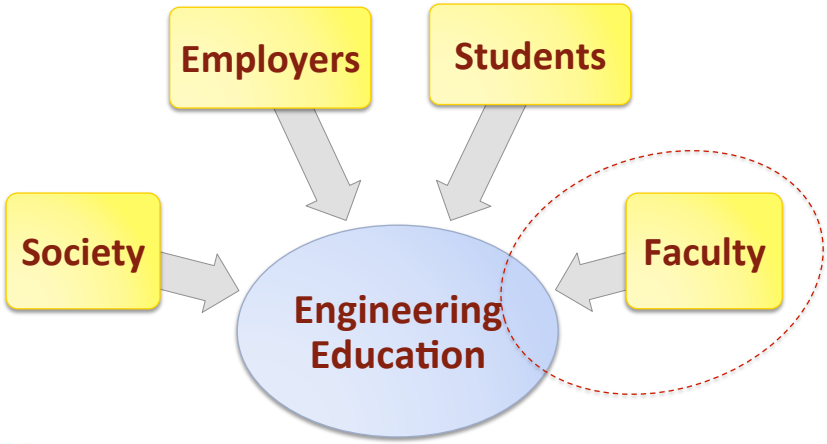
Educate <u>for the context</u> of
Engineering

CDIO Standard 1 – The context
Adoption of the principle that product, process, and system lifecycle development and deployment – *Conceiving, Designing, Implementing and Operating* – are the context for engineering education.

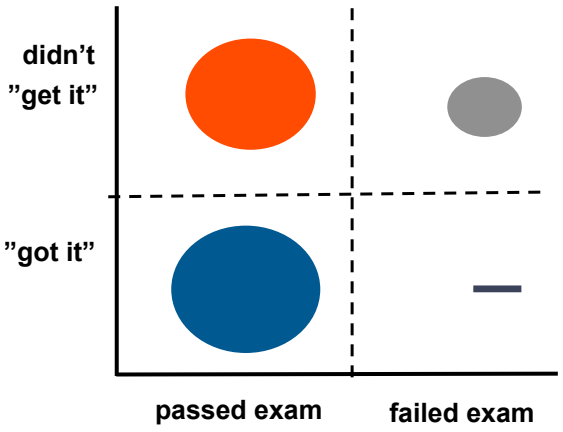
NECESSARY BUT NOT SUFFICIENT

Engineers who can engineer!

But what if we do ask faculty?



Deeper working knowledge of disciplinary fundamentals



- Functional knowledge
- Not just reproduction of known solutions to known problems
- Conceptual understanding
- Being able to explain what they do and why

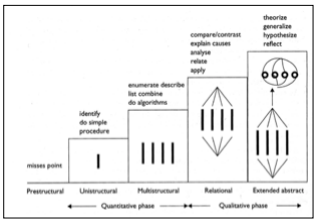
See for instance Mazur, E. (1997) *Peer Instruction*, and Kember & McNaught (2007) *Enhancing University Teaching*.

Quality of student learning – more useful classifications

Feisel-Schmitz Technical Taxonomy

Judge	To be able to critically evaluate multiple solutions and select an optimum solution
Solve	Characterize, analyze, and synthesize to model a system (provide appropriate assumptions)
Explain	Be able to state the process/outcome/ concept in their own words
Compute	Follow rules and procedures (substitute quantities correctly into equations and arrive at a correct result, "plug & chug")
Define	State the definition of the concept or describe in a qualitative or quantitative manner

The SOLO Taxonomy



[Feisel, L.D., Teaching Students to Continue Their Education, *Proceedings of the Frontiers in Education Conference*, 1986.]

What is CDIO?

2. A methodology for engineering education reform

The 12 CDIO Standards

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The educational development process is the working definition of CDIO:

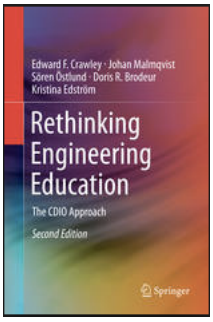
The CDIO Standards

Context:
- Recognise that we educate for the practice of engineering [1]

Curriculum development:
- Formulate explicit program learning outcomes (including engineering skills) in dialogue with stakeholders [2]
- Map out responsibilities to courses – negotiate intended learning outcomes [3]
- Evaluation and continuous programme improvement [12]

Course development, discipline-led and project-based learning experiences:
- Introduction to engineering [4]
- Design-implement experiences and workspaces [5, 6]
- Integrated learning experiences [7]
- Active and experiential learning [8]
- Learning assessment [11]

Faculty development
- Engineering skills [9]
- Skills in teaching & learning , and assessment [10]



Crawley, et al (2007, 2014) *Rethinking Engineering Education: The CDIO Approach*, Springer.

CDIO Standard 2: Learning Outcomes

Recognising the dual nature of learning

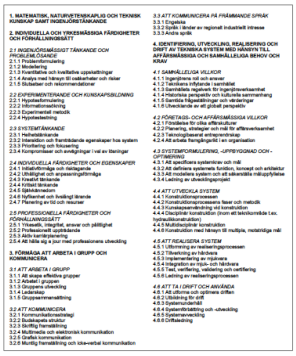
Understanding of technical fundamentals and **Professional engineering skills**

CDIO Standard 2 – Learning Outcomes
Specific, detailed learning outcomes for personal and interpersonal skills, and product, process, and system building skills, as well as disciplinary knowledge, consistent with program goals and validated by program stakeholders.

The CDIO Syllabus

Support in formulating learning outcomes

Each institution formulates program goals considering their own stakeholder needs, national and institutional context, level and scope of programs, subject area, etc



The CDIO Syllabus

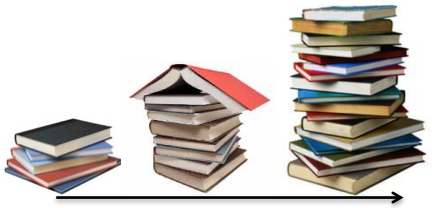
- is not prescriptive (not a CDIO Standard)
- is offered as an instrument for specifying local program goals by selecting topics and making appropriate additions in dialogue with stakeholders
- lists and categorises desired qualities of engineering graduates
- is based on stakeholder input and validation

- Crawley, E. F. 2001. *The CDIO Syllabus: A Statement of Goals for Undergraduate Engineering Education: see* www.cdio.org/framework-benefits/cdio-syllabus-report
- for version 2.0, see Crawley, Malmqvist, Lucas, and Brodeur. 2011. "The CDIO Syllabus v2.0. An Updated Statement of Goals for Engineering Education." *Proceedings of the 7th International CDIO Conference*

The strategy of CDIO is integrated learning of knowledge and skills

Standard 3 – Integrated curiculum

Integrating the two learning processes



Acquisition of technical knowledge

Development of engineering skills

The CDIO strategy is the **integrated curriculum** where knowledge & skills give each other meaning!

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

Every learning experience sets a balance and relationship



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 PROBLEM/PRACTICE

- Working understanding = capability to apply, functioning knowledge
- Seeing the knowledge through the lense 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

Systematic assignment of programme learning outcomes to learning activities - negotiating the contribution

Development routes (schematic)				
Year 1	Introductory course	Physics	Mathematics I	
	Mechanics I	Mathematics II	Numerical Methods	
Year 2	Mechanics II	Solid Mechanics	Product development	
	Thermodynamics	Mathematics III	Fluid mechanics	Sound and Vibrations
Year 3	Control Theory	Electrical Eng.	Statistics	Signal analysis
	Oral communication	Written communication	Project management	Teamwork

Example: Communication skills in Lightweight design

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.

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

"It's about educating engineers who can actually engineer!"

What does communication skills mean in the specific professional role or subject area?

[Barrie 2004]

Place in curriculum	Faculty perception of generic skills and attributes
Integral	They are integral to disciplinary knowledge, infusing and **ENABLING** scholarly learning and knowledge.
Application	They let students make use of or apply disciplinary knowledge, thus potentially changing and **TRANSFORMING** disciplinary knowledge through its application. Skills are closely related to, and parallel, discipline learning outcomes.
Associated	They are useful additional skills that **COMPLEMENT** or round out discipline knowledge.They are part of the university syllabus but separate and secondary to discipline knowledge.
Not part of curriculum	They are necessary basic **PRECURSOR** skills and abilities. We may need remedial teaching of such skills at university.

Barrie, S. (2004) A research-based approach to generic graduate attributes policy, *Higher Education Research and Development*. 23 (3), 261-275

Engineering skills - implications

- **It's not about "soft skills"**
  Personal, interpersonal, product, process, and system building skills are **intrinsic to engineering** and we should recognise them as **engineering skills**.
- **It's not about "adding more content"**
  Students must be given opportunities to develop communication skills, teamwork skills, etc. This is best achieved through **practicing, reflecting, giving and receiving feedback** (rather than lecturing on psychological and social theory).
- **It's not about "wasting credits"**
  When students practice engineering skills they apply and express their technical knowledge. As they expose their understanding among peers, doing well will also matter more to them. Students will develop **deeper working knowledge**.
- **It's not about appending "skills modules"**
  Personal, interpersonal, product, process, and system building skills must be practiced and assessed **in the technical context**, it cannot be done separately.

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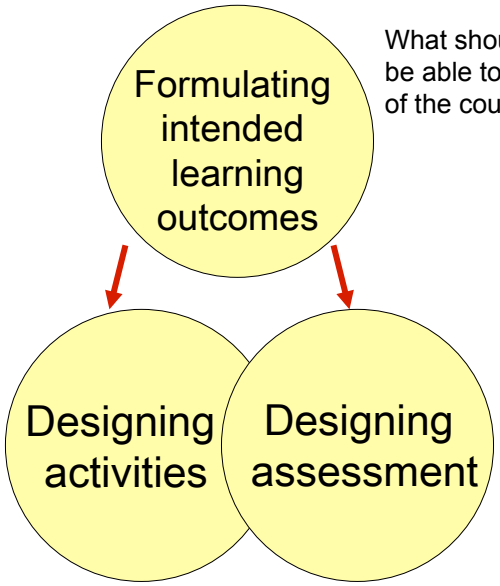
Course Design for Integrated Learning

Learning outcomes are the basis for course design



What should the students be able to do as a result of the course?

Constructive alignment [Biggs]

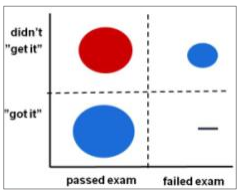
What work is appropriate for the students to do, to reach the learning outcomes?

What should the students do to demonstrate that they fulfil the learning outcomes?

Constructive alignment - applied

Formulating intended learning outcomes

What should the students be able to do as a result of the course?



Designing activities

Designing assessment

What work is appropriate for the students to do, to reach the learning outcomes?

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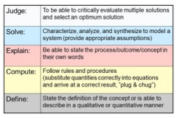
Constructive alignment - applied



Formulating intended learning outcomes

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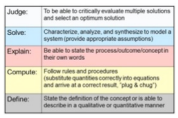

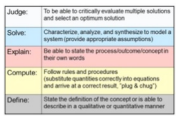

Designing activities

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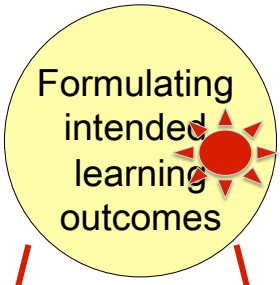

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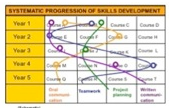


CDIO Standard 7 – Integrated Learning Experiences
Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal and interpersonal skills, and product, process, and system building skills.

CDIO Standard 8 – Active Learning
Teaching and learning based on active and experiential learning methods

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

Anyone can improve a course if it means that the teacher works 100 hours more

That is not a valid solution…

This is about how to get better student learning from the same (finite) teaching resources

CDIO Standard 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.

What if we were building a bridge…

Maidenhead Railroad Bridge, England, I. K. Brunel, 1838.

What is it that we have today that keeps us from replicating the old bridge?

Competence

Öresund Bridge, George Rotne, 2000.

The first strategy is to use existing resources better

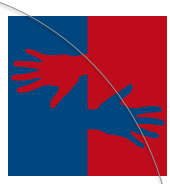
- re-task the space you already have
- re-task the time you already have

If you can not control the resources you have, how can you ever justify why you should get more resources – it would only result in ”more of the same”

Examples are illustrations of principles

A specific **example** will **illustrate** **generic principles** to **inspire** **applications** - of many different kinds.

Educational development in CDIO



Improving discipline-led learning

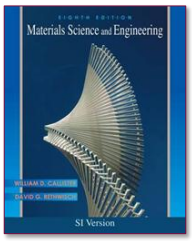
- Improving the quality of understanding
- Knowledge prepared for use: seeing the knowledge through the lense of problems
- Ability to communicate and collaborate
- Interconnecting the disciplines

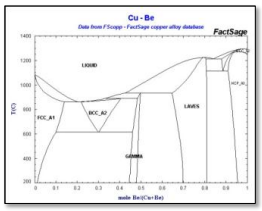
Improving problem/practice-based learning

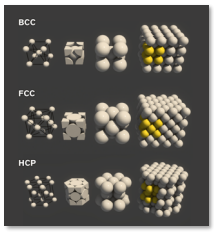
- Adding problem/practice-based learning experiences
  - Early engineering experience
  - A sequence of Design-Implement Experiences
- Improving reflection and learning
- Improving cost-effectiveness of teaching

A course in Basic Materials Science

- Standard lecture based course
- Focus on disciplinary knowledge ("content")







Hypoeutectoid steel was quenched from austenite to martensite which was tempered, spheroidized and hardened by dislocation pinning..

[Professor Maria Knutson Wedel, Chalmers]

Two ways of seeing materials science

From the inside - out

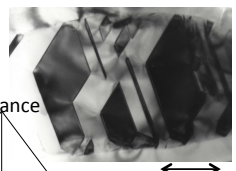
"Materials engineers distinguish themselves from mechanical engineers by their focus on the internal structure and processing of materials, specifically at the micro- and nano-scale."

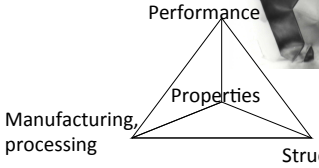
Flemings & Cahn

From the outside - in

"Materials have a supportive role of materializing the design. The performance is of primary concern, followed by considerations of related materials properties…."

Östberg





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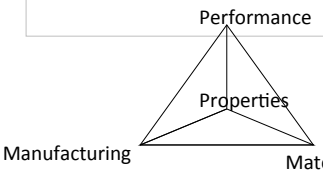


[Professor Maria Knutson Wedel, Chalmers]

A course in Basic Materials Science

Implications I
- formulating intended learning outcomes

Old learning objectives (the disciplinary knowledge in itself)

…describe crystal structures of some metals…

…interpret phase diagrams…

…explain hardening mechanisms…

...describe heat treatments…

New learning objectives (performances of understanding)

…select materials based on considerations for functionality and sustainability

...explain how to optimize material dependent processes (eg casting, forming, joining)

...discuss challenges and trade-offs when (new) materials are developed

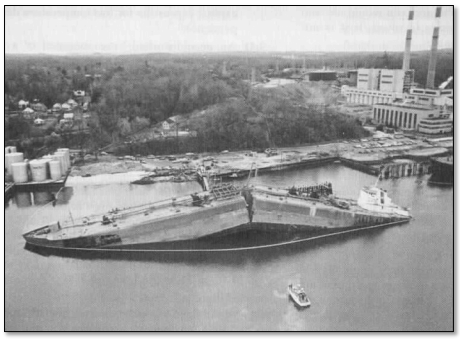
...devise how to minimise failure in service (corrosion, creep, fractured welds)

[Professor Maria Knutson Wedel, Chalmers]

A course in Basic Materials Science

Implications II
- design of learning activities

Still lectures and still the same book, but framed differently:
- from product to atoms
- focus on engineering problems



And…
- Study visit in industry, assessed by written reflection
- Material selection class (CES)
- Active lecturing: buzz groups, quizzes
- Test yourself on the web
- Students developed animations to visualize

[Professor Maria Knutson Wedel, Chalmers]

A course in Basic Materials Science

Implications III - design of assessment

2011:

New type of exam, aimed at deeper working understanding

- More **open-ended questions** - many solutions possible, the quality of **reasoning** is assessed
- **Interconnected knowledge** – several aspects need to be integrated

➢*Very good results on the exam but some students were scared and there were many questions beforehand…*

2012:

Added formative midterm exam, with peer assessment

- Communicates expectations on the required **level and nature of understanding** (Feedback / Feed forward)
- Generates **appropriate learning activity**
- **Early engagement in the basics** of the course (a basis for further learning)

[Professor Maria Knutson Wedel, Chalmers]

Educational development in CDIO

In disciplinary courses

- Improving the quality of understanding
- Knowledge prepared for use: seeing the knowledge through the lense of problems
- Ability to communicate and collaborate
- Interconnecting the disciplines

In problem/practice-based courses

- Adding problem/practice-based learning experiences
  - Early engineering experience
  - A sequence of Design-Implement Experiences
- Improving reflection and learning
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Design-Implement Experiences

student teams design and implement actual products, processes, or systems

- Projects take different forms in various engineering fields
- The essential aim is to learn through near-authentic engineering tasks, working in modes resembling professional practice

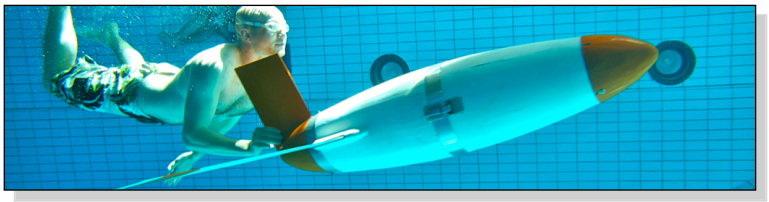
CDIO Standard 5 – Design-Implement Experiences
A curriculum that includes two or more design-implement experiences, including one at a basic level and one at an advanced level.

- Progression in several dimensions
  - engineering knowledge (breadth and depth)
  - size of student teams
  - length of project
  - increasingly complex and open-ended problems
  - tensions, contextual factors
  - student and facilitator roles

Learning in Design-Implement Experiences

- *The purpose is not to build things, but to **learn** from building things*

- it is key that students bring their designs and solutions to an **operationally testable state**.
- To turn practical experiences into learning, students are continuously guided through **reflection and feedback exercises** supporting them to evaluate their work and identify potential improvement of results and processes.
- **Assessment and grading** should reflect the quality of attained **learning outcomes**, rather than the product performance in itself



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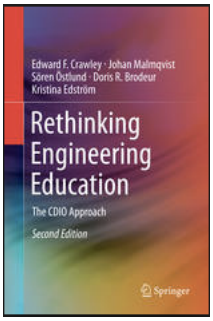
- Skills in teaching & learning , and assessment [10]

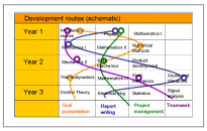


Crawley, et al (2007, 2014) *Rethinking Engineering Education: The CDIO Approach*, Springer.

CDIO integrated curriculum development

- the process in a nutshell

- **Set program learning outcomes**
  in dialogue with stakeholders
- **Design an integrated curriculum**
  mapping out responsibilities to courses
  – negotiate intended learning outcomes
  (both knowledge and engineering skills)



- **Create integrated learning experiences**
  course development with constructive alignment
  - ✓ mutually supporting **subject courses**
  - ✓ applying **active learning methods**
  - ✓ an **introductory course**
  - ✓ a sequence of **design-implement experiences**

- **Faculty development**
  - ✓ Engineering skills
  - ✓ Skills in teaching, learning and assessment
- **Evaluation** and continuous **improvement**

What is CDIO?

3. A community to learn together and to share experience

The CDIO Initiative

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CDIO as a community – the CDIO Initiative

- **The CDIO Initiative** started in 2000 as a project:
  Partners: MIT, KTH, Chalmers, Linköping University
- Soon other institutions expressed an interest in joining, today **more than 100 CDIO Collaborators** worldwide

CDIO is an international community

North America:
- Massachusetts Institute of Technology
- U. S. Naval Academy
- Daniel Webster College
- Duke University
- California State U Northridge
- University of Colorado
- Arizona State University
- University of Michigan
- Pennsylvania State University
- Embry-Riddle University
- LASPAU
- Naval Postgraduate School
- University of Notre Dame
- Stanford University
- University of Calgary
- École Polytechnique de Montréal
- Queen's University
- University of Manitoba

Latin America:
- Universidad de Chile
- Universidad de Santiago de Chile
- Universidad Católica de la Santisima Concepción
- Pontificia Universidad Javeriana
- Universidad Nacional de Colombia
- Universidad ICESI
- UNITEC

Africa:
- University of Pretoria
- ESPRIT, Tunisia

For an updated list see www.cdio.org

UK-Ireland:
- Queen's University Belfast
- University of Liverpool
- Lancaster University
- University of Bristol
- University of Leeds
- Aston University
- University of Strathclyde
- University of Leicester
- University of Limerick
- Trinity College Dublin

Asia:
- Shantou University
- Beijing Jiaotong University
- Beijing Institute of Petrochemical Technology
- Tsinghua University
- Qinggong College, Hebei United University
- Chengdu University of Information Technology
- Dalian Neusoft Institute of Information
- Suzhou Industrial Park Institute of Vocational Technology
- Beijing Institute of Petrochemical Technology
- Singapore Polytechnic
- Nanyang Polytechnic
- Taylor's University College
- Vietnam National University, Ho Chi Minh City
- Duy Tan University
- Kanazawa Technical College
- Kanazawa Institute of Technology

Australia:
- Queensland University of Technology
- Australasian Association for Engineering Education
- University of Sydney
- The Chisholm Institute
- University of Auckland

Europe:
- Chalmers University of Technology
- KTH- Royal Institute of Technology
- Linköping University
- Jönköping University
- Umeå University
- Linnaeus University
- University of Skövde
- Group T – International University College Leuven
- Hogeschool Gent
- Technical University of Denmark
- Aarhus University School of Engineering
- Aalborg University
- Delft University of Technology
- RWTH Achen
- Hochschule Wismar
- Helsinki Metropolia University of Applied Sciences
- Turku University of Applied Sciences
- Seinäjoki University of Applied Sciences
- Lahti University of Applied Sciences
- Kemi-Tornio University of Applied Science
- Savonia University of Applied Science
- University of Turku
- Novia University of Applied Science
- Gdansk University of Technology
- Instituto Superior de Engenharia do Porto
- Politecnico di Milano
- Telecom Bretagne
- Universitat Politècnica de Catalunya
- AFEKA Tel Aviv Academic College of Engineering
- SCE Shamoon College of Engineering
- Tomsk Polytechnic University
- Astrakhan State University
- Skolkovo Institute of Science and Technology
- Tomsk State University of Control Systems and Radioelectronics (TUSUR)
- Moscow Aviation Institute
- Moscow Institute of Physics and Technology
- Vilniaus Kolegija/University of Applied Sciences
- University of Reykjavik
- Ernst-Abbe-University of Applied Sciences Jena

Annual International CDIO Conference

2005 Queen's University, Kingston, Canada

2006 Linköping University, Linköping, Sweden

2007 Hogeschool Gent, Gent, Belgium

2008 MIT, Cambridge MA, USA

2009 Singapore Polytechnic, Singapore

2010 École Polytéchnique, Montreal, Canada

2011 Denmark Technical University, Copenhagen, Denmark

2012 Queensland University of Technology, Brisbane, Australia

2013 Harvard/MIT, Cambridge MA, USA

2015 UPC, Barcelona, Spain

www.cdio.org

Next:
- **11th International CDIO Conference** June 2015, Chengdu, China
- **12th International CDIO Conference** June 2016, Turku, Finland

Chalmers has taken the lead

CDIO Office

Johan Malmqvist

Jenny Netzler

What is CDIO?

1. **An idea** of what engineering students should learn:
   "Engineers who can engineer"
2. **A methodology** for engineering education reform:
   The twelve **CDIO Standards**
3. **A community** to learn and share the experience:
   The **CDIO Initiative**

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