The CDIO approach for engineering education development

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Kristina Edström
Engineer & Educational developer
- M.Sc. in Engineering, Chalmers
- Associate Professor in Engineering Education Development at KTH Royal Institute of Technology, Stockholm, Sweden
- 700 participants in the course Teaching and Learning in Higher Education, 7.5 ECTS, customized for KTH faculty, 2004-2012
- Director of Educational Development at Skolkovo Institute of Science and Technology, Moscow, 2012-2013

Strategic educational development, national and international
- CDIO Initiative for reform of engineering education since 2001
- SEFI Administrative Council, 2010-2013

Research
- PhD defense December 13, 2017
- Editor-in-Chief of the European Journal of Engineering Education from 2018
“If you want to learn about a system, try to change it”

(attributed to Kurt Lewin)

CDIO – the community

The CDIO Initiative
CDIO as a community – the CDIO Initiative

- The CDIO Initiative started in 2000 as a project:
  Partners: MIT, KTH Royal Institute of Technology, Chalmers, and Linköping University
  Soon other institutions expressed an interest in joining
  Today more than 140 CDIO Collaborators worldwide

The international CDIO community

North America
- Arizona State University
- California State University, Northridge
- Dalhousie University
- Chalmers University of Technology
- Ecole Polytechnique de Montreal
- Embry-Riddle Aeronautical University - LAPE
- Massachusetts Institute of Technology
- Naval Postgraduate School (U.S.)
- Pennsylvania State University
- Queen’s University (Canada)
- Sheridan College
- Stanford University
- University of Arkansas
- University of Calgary
- University of Colorado
- University of Manitoba
- University of Notre Dame
- University of North Dakota
- University of Pretoria
- University of Queensland
- Curtin University
- University of Sydney
- University of the Sunshine Coast

Asia
- Beijing Institute of Petrochemical Technology
- Beijing Jiaotong University
- Changsha University of Information Technology
- Chulalongkorn University, Thailand
- Dhaka University of Engineering & Technology
- Dalian University of Information Science and Technology
- Duy Tan University, Vietnam
- FPT University, Vietnam
- IIT Kanpur, India
- Kajosaens Institute of Technology
- Kajosaens Technical College
- Kajosaens University of Science and Technology
- Kajosaens Polytechnic
- PaoShan University (China)
- Rajamangala University of Technology Roi Et (RMUTR)
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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 Polytechnique, Montreal, Canada
2011 Denmark Technical University, Copenhagen, Denmark
2012 Queensland University of Technology, Brisbane, Australia
2013 Harvard/MIT, Cambridge MA, USA
2014 UPC, Barcelona, Spain
2015 CUIT, Chengdu, China
2016 Turku UAS, Turku, Finland
2017 University of Calgary, Canada

www.cdio.org

Next:
- European CDIO Regional meeting
  January 2017, Skolkovo, Moscow, Russia
- 14th International CDIO Conference
  June 2018, Kanazawa, Japan
- 15th International CDIO Conference
  June 2019, Aarhus, Denmark

CDIO – the idea
What engineering students should learn and why

“Engineers who can engineer”
Stakeholder perspectives

External
(care mainly about results)

Employers

Students

Internal
(care about both process and results)

Society

Engineering
Education

An education about technology

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

An education in engineering

NECESSARY BUT NOT SUFFICIENT
Disciplinary theory applied to “problem-solving”

Theory and judgement applied to 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


Individual approach

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
CDIO Standard 1: The context

*Educating for the context of engineering*

**Education set in**

*Engineering science*

**Educate for the context**

*of Engineering*

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**NECESSARY BUT NOT SUFFICIENT**

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**Engineers who can engineer!**

But what if we do ask faculty?

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[Society](#) ❯ [Engineering Education](#) ❯ [Employers](#) ❯ [Students](#) ❯ [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

Quality of student learning – Feisel-Schmitz Technical Taxonomy

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

CDIO the methodology

The 12 CDIO Standards

Success
is never inherent in a method;
it always depends on
good implementation.
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]

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

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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


The strategy of CDIO is integrated learning of knowledge and skills
Standard 3 – Integrated curriculum
*Integrating the two learning processes*

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.

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Every learning experience sets a balance and relationship

**Discipline-led learning**
- Well-structured knowledge base
- Evidence/theory, Model/reality
- Methods to further the knowledge frontier

**CONNECTING WITH PROBLEM/PRACTICE**
- Deep working understanding = ability to apply
- 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, trade-offs
- Context
- Professional work processes
- “Creating that which has never been”

**CONNECTING WITH DISCIPLINARY KNOWLEDGE**
- Discovering how the disciplinary knowledge is useful
- Reinforcing disciplinary understanding
- Motivational context
Systematic assignment of program learning objectives to courses - negotiating the contribution

<table>
<thead>
<tr>
<th>Development routes (schematic)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Year 1</strong></td>
</tr>
<tr>
<td>Introduction course</td>
</tr>
<tr>
<td>Mechanics I</td>
</tr>
<tr>
<td><strong>Year 2</strong></td>
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<tr>
<td>Mechanics II</td>
</tr>
<tr>
<td>Thermodynamics</td>
</tr>
<tr>
<td><strong>Year 3</strong></td>
</tr>
<tr>
<td>Control Theory</td>
</tr>
<tr>
<td>Oral communication</td>
</tr>
</tbody>
</table>

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]

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**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.
Course Design for Integrated Learning

Learning outcomes are the basis for course design.

Formulating intended learning outcomes

Designing activities

Designing assessment

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

How should the students demonstrate that they fulfil the learning outcomes?

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

Constructive alignment [Biggs]
What work is appropriate for the students to do, to reach the learning outcomes?

How should the students demonstrate that they fulfil the learning outcomes?

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

Constructive alignment - applied

Formulating intended learning outcomes

Designing activities

Designing assessment

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Constructive alignment - applied

Formulating intended learning outcomes

Designing activities

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

Constructive alignment - applied

Formulating intended learning outcomes

Designing activities

Designing assessment

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.
Examples are illustrations of principles

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

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Educational development strategies

**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]

A course in Basic Materials Science

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

[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 minimize failure in service (corrosion, creep, fractured welds)

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
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)

Educational development strategies

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
- Improving cost-effectiveness of teaching
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

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

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.

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
The educational development process is the working definition of CDIO:

**The CDIO Standards**

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**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**
How to become a CDIO Collaborator

1. Express an interest (answer a few questions)
   - Why does your university want to join the CDIO initiative?
   - Which of your programs do you plan to initially apply CDIO? How do you expect CDIO to influence these programs?
   - What goals do you hope to achieve?
   - What are your plans for participating with the other CDIO collaborating schools?
   - What experience do you have in engineering educational reform at your university, which might contribute to the effort and form a foundation for the work as a collaborator?
   - What level of commitment and support do you have from your university’s Dean and Central Leadership?
   - Who will be the key two to five participants in your effort?

2. Make introductions at a CDIO meeting

3. The CDIO Council will grant collaborator status

   - Contact the leader of your region, to get started.
     (see www.cdio.org)

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