Curriculum and course development with CDIO

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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, Sweden
  - 2012-2013 also Director of Educational Development at Skoltech, Russia

- Strategic educational development in Sweden and internationally
  - CDIO Initiative for reform of engineering education since 2001
  - SEFI Administrative Council 2010-2013

- Faculty development at KTH
  - During 2004-2012, more than 600 participants have taken the course *Teaching and Learning in Higher Education* (7.5 ECTS credits) customized for faculty at KTH
Designing the CDIO curriculum
– the CDIO Standards

Now:
- Designing an integrated curriculum

After lunch:
- Course design for integrated learning

Success is not inherent in a method;
it always depends on good implementation.
1. Designing an Integrated Curriculum

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]

Step 1
Find out your stakeholder perspectives

Employers  Students

Society  Faculty

Engineering Education

Work life skills

“Problem-solving”  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

NECESSARY BUT NOT SUFFICIENT
Work life skills

Technology in itself

Working in the engineering 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

NECESSARY BUT NOT SUFFICIENT

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

NECESSARY BUT NOT SUFFICIENT
CDIO Standard 1: The context
_Educating for the context of engineering_

**Education based in**
*Engineering science*

**Educate for the context of**
*Engineering*

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**NECESSARY BUT NOT SUFFICIENT**

But what if we do ask faculty?

Employers  
Students

Society  
Faculty

**Engineering Education**
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 – more useful classifications

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

(Feisel, L.D., Teaching Students to Continue Their Education, Proceedings of the Frontiers in Education Conference, 1986.)
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 based on stakeholder input and validation
- 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

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**

...because we need to improve both learning processes – not one at the expense of the other

...because 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 professional skills**
- 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

<table>
<thead>
<tr>
<th>Year 1</th>
<th>Course A</th>
<th>Course B</th>
<th>Course C</th>
<th>Course D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 2</td>
<td>Course E</td>
<td>Course F</td>
<td>Course G</td>
<td>Course H</td>
</tr>
<tr>
<td>Year 3</td>
<td>Course I</td>
<td>Course J</td>
<td>Course K</td>
<td>Course L</td>
</tr>
<tr>
<td>Year 4</td>
<td>Course M</td>
<td>Course N</td>
<td>Course O</td>
<td>Course P</td>
</tr>
<tr>
<td>Year 5</td>
<td>Course Q</td>
<td>Course R</td>
<td>Course S</td>
<td>Course T</td>
</tr>
<tr>
<td></td>
<td><strong>Oral communication</strong></td>
<td><strong>Teamwork</strong></td>
<td><strong>Project planning</strong></td>
<td><strong>Written communication</strong></td>
</tr>
</tbody>
</table>

(Schematic)
Example:
Communication skills in the course ‘Lightweight structures and FEM’

Communication in lightweight structures 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]
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.

<table>
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<tr>
<th>Place in curriculum</th>
<th>Faculty perception of generic skills and attributes</th>
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<tr>
<td>Integral</td>
<td>They are integral to disciplinary knowledge, infusing and ENABLING scholarly learning and knowledge.</td>
</tr>
<tr>
<td>Application</td>
<td>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.</td>
</tr>
<tr>
<td>Associated</td>
<td>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.</td>
</tr>
<tr>
<td>Not part of curriculum</td>
<td>They are necessary basic PRECURSOR skills and abilities. We may need remedial teaching of such skills at university.</td>
</tr>
</tbody>
</table>

Integrated program descriptions


Program description – sample

VEHICLE ENGINEERING – KTH

Table of contents
Introduction
Program goals
Engineering skills (CDIO Syllabus to second level of detail and associated expected proficiencies)

Program structure
Program plan
Explicit disciplinary links between courses
Program design matrix
Sequences for selected engineering skills

All courses in program
Intended learning outcomes
Contribution to engineering skills
Sequencing the curriculum
THE BLACK-BOX EXERCISE

INPUT:
Previous knowledge and skills

OUTPUT:
Contribution to final learning outcomes
Input to later course
Input to later course

All courses are presented through input and output only:

- Enables efficient discussions
- Makes connections visible (as well as lack thereof)
- Gives all faculty an overview of the program
- Serves as a basis for improving coordination
- Use for adjusting intentions in planning phase
- Use for checking existing programs

Course Design for Integrated Learning
Learning outcomes are the basis for course design

Formulating intended learning outcomes

Designing activities

Designing assessment

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?

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

Constructive alignment [Biggs]

Constructive alignment - applied

Formulating intended learning outcomes

Designing activities

Designing assessment

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?

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

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.

Remember that we are developing people as much as we are developing programs.
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

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 (e.g., casting, forming, joining)
...discuss challenges and trade-offs when (new) materials are developed
...devise how to minimize failure in service (corrosion, creep, fractured welds)
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

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 in CDIO

In disciplinary courses
- Improving the quality of understanding
- Knowledge prepared for use: seeing the knowledge through the lens 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

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
The educational development process is the working definition of CDIO:

The CDIO Standards

**Context:**
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