Integrating project-led and discipline-led learning
– the CDIO approach

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cdio
CONCEIVE DESIGN IMPLEMENT OPERATE

Who is Kristina Edström?

- **Engineer & Educational developer**
  - M. Sc. in Engineering, Chalmers
  - Lecturer in Engineering Education Development at KTH
  - Director of Educational Development at Skolkovo Tech
- **Strategic educational development at KTH, in Sweden and internationally**
  - CDIO Initiative for reform of engineering education since 2001
  - SEFI Administrative Council since 2010
- **Faculty development at KTH**
  - During 2004-2012, more than 600 participants have taken *Teaching and Learning in Higher Education* (7.5 ECTS credits) customized for faculty at KTH

CONCEIVE DESIGN IMPLEMENT OPERATE

"Education of engineers had become disassociated from the practice of engineering" (Crawley 2001)

Stakeholder input on *what* engineers should be able to do:

- Industry feedback on requirements for engineers (Gordon 1984; Boeing 1996; Augustine 1996)
- Learning outcomes in accreditation standards (ABET EC 2000)

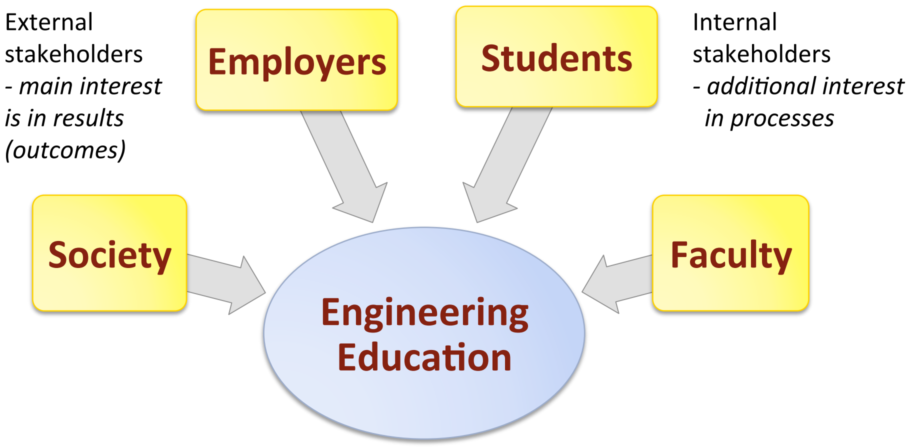
Two central questions

Who should have a say in this matter?

1. What knowledge, skills and attitudes should students possess as they graduate from our programs?
2. How can we do better at ensuring that students learn these skills?

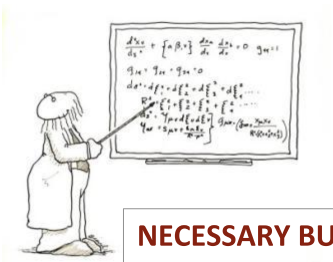
Massachusetts Institute of Technology

Stakeholder perspectives



Work life perspective I

Disciplinary theory applied to "Problem-solving"



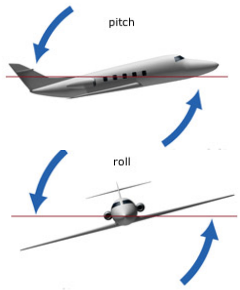
NECESSARY BUT NOT SUFFICIENT

Theory and judgement applied to <u>real</u> problems

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

Work life perspective II

Bare artefact



NECESSARY BUT NOT SUFFICIENT

Conceive – Design – Implement – Operate

Conceive: customer needs, technology, enterprise strategy, regulations; and conceptual, technical, and business plans

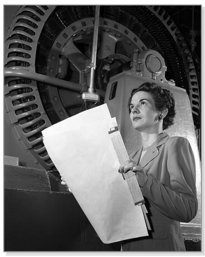
Design: plans, drawings, and algorithms that describe what will be implemented

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

Work life perspective III

Individual approach



NECESSARY BUT NOT SUFFICIENT

Communicative and collaborative approach

- Technology sits in a social context
- Engineering work processes are social activities involving customers, suppliers, colleagues, citizens, authorities, competitors
- Networking within and across organizational boundaries, in a globalised world
- Collaboration is much more than just being able to work in project teams with well-defined tasks
- Communication is more than just presentation skills – dialogue is crucial

Work life perspective (conclusion)

Education set in
the context of:
Engineering science

NECESSARY BUT
NOT SUFFICIENT

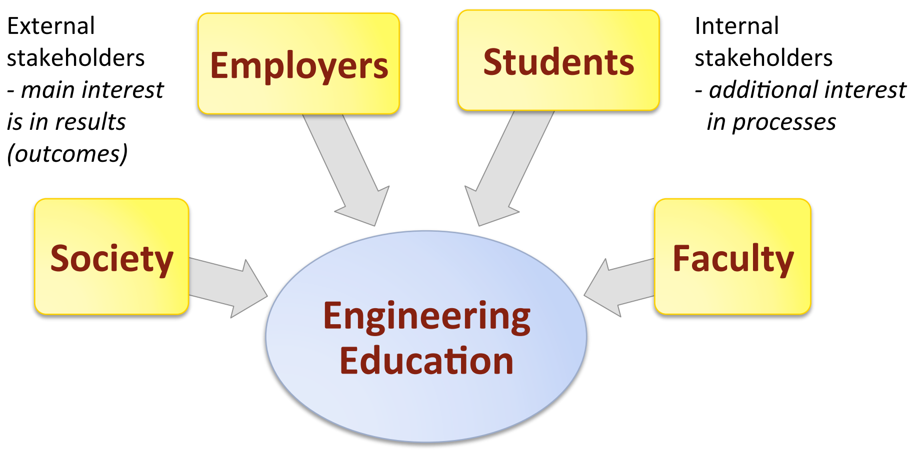
Educate for
the context of:
Engineering

- *Engineers who can engineer!*

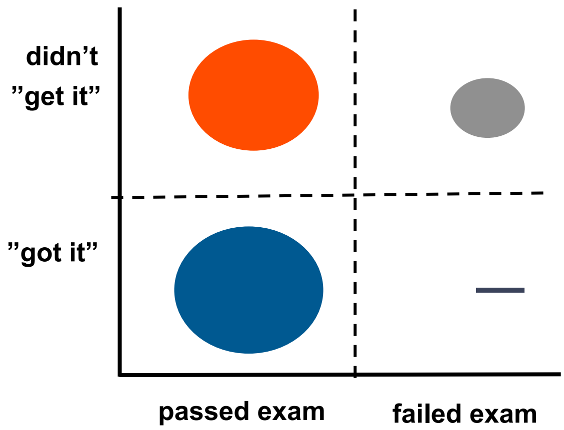
This calls for using a problem-led and project-based approach

BUT…

Stakeholder perspectives



Quality of student learning



Conceptual understanding

- Not just reproduction of known solutions to known problems
- Being able to explain what they do and why
- Deeper working disciplinary knowledge

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

The dual nature of learning
for professional practice, research, innovation

The knowledge of the disciplines and **The skills of problem-solving / practice**

We need to do well with both components – they give meaning to each other!

Recognising the dual nature of engineering education

Knowledge

&

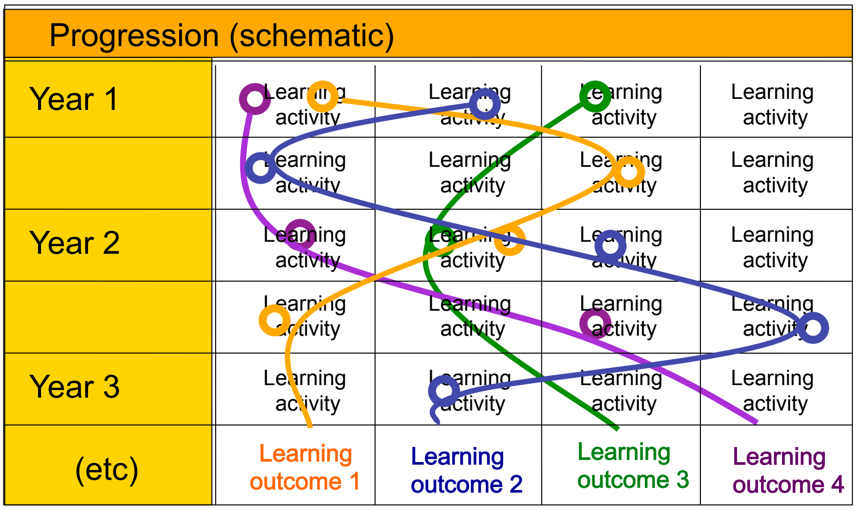
skills

…give each other meaning!

The strategy of CDIO is integrated learning of knowledge and skills

!

Negotiating the contribution – Systematic assignment of programme learning outcomes to learning activities



Enabling skills

Communication means being able to

- ► use the technical concepts comfortably,
- ► discuss a problem at different levels,
- ► determine what is relevant to the situation,
- ► argue for or against conceptual ideas and solutions,
- ► develop ideas through discussion and collaborative sketching,
- ► explain the technical matters for different audiences,
- ► show confidence in expressing yourself within the field...

Communication skills as contextualized competences are **embedded** in, and **inseparable** from, students' application of technical knowledge.

The same kind of reasoning can be made for teamwork, ethics (etc...) as well.

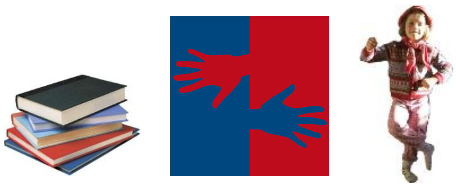
This is not about adding "soft skills" – it is about students becoming professional!

”Contextualised”
What does communication skills mean within the specific professional role or subject area?

Place in curriculum	Faculty perception of generic graduate 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,(2004) A research-based approach to generic graduate attributes policy

Every learning experience sets a balance and relationship



Discipline-led learning

- Well-structured knowledge base (”content”)
- Knowing what is known and what is not
- Critical thinking, intellectual skills
- Methods to further the knowledge frontier

GRABBING INTO PROBLEM-LED LEARNING

- Deeper working understanding
- Capability to apply, functioning knowledge, seeing the knowledge through the lense of problems
- Communication and collaboration skills
- Interconnecting the disciplines

Problem/practice-led learning

- Integration and application of knowledge, synthesis
- Open-ended problems, ambiguity, conflicting interests, trade-offs
- Working under conditions of contexts
- Professional skills (work processes, habits)
- ”Creating that which has never been”
- Knowledge building of the practice

GRABBING INTO DISCIPLINARY LEARNING

- Drawing on the disciplinary knowledge
- Reinforcing disciplinary understanding
- Motivation for disciplinary knowledge

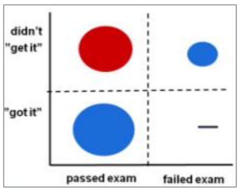
EFFECTIVE IMPLEMENTATION STRATEGIES

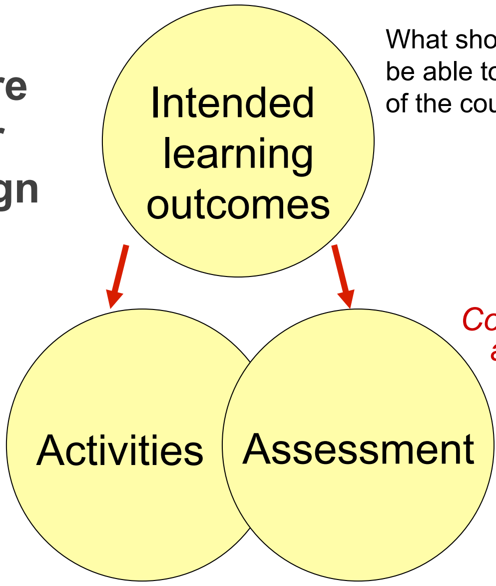
Anyone can improve a course if it means that the teacher should work 100 hours more… not a valid solution.

This is about how to get **the best student learning** with a given level of **teaching resources**

Then we need pedagogical know-how!

Learning outcomes are the basis for course design





What should the <u>students</u> be able to do as a result of the course?

Constructive alignment [Biggs]

What work is appropriate for the <u>students</u> to do, to reach the learning outcomes?

What should the <u>students</u> do to demonstrate that they fulfil the learning outcomes?

[Biggs and Tang (2011) Teaching for Quality Learning at University]

Examples are illustrations of principles

A specific **example**

will **illustrate**

generic principles

to **inspire**

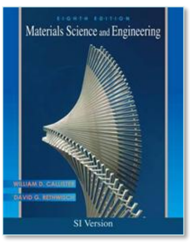
applications - of many different kinds.

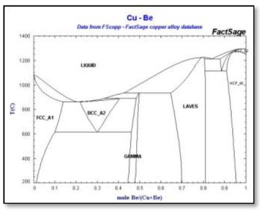
How discipline-led courses must contribute

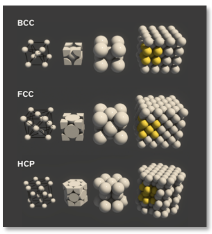
- Improved quality of understanding
- Knowledge available for use: seeing the knowledge through the lense of problems
- Ability to communicate and collaborate
- Interconnecting the disciplines

Example: Discipline-led course Materials Science

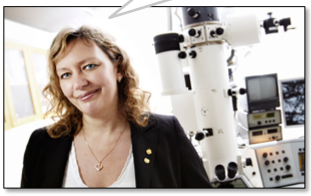
- Standard lecture based course
- Focus on disciplinary knowledge (“content”)







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



[Professor Maria Knutson Wedel, Chalmers]

Example – a course in Materials Science

Two ways of seeing materials science

From the inside - out

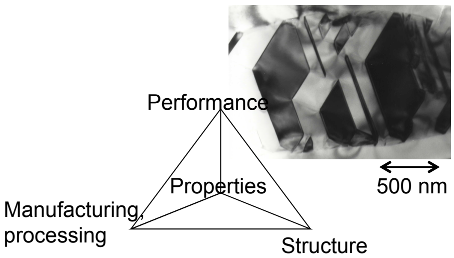
"Materials engineers distinguish themselves from mechanical engineers by their focus on the internal structure and processing of materials, specifically at the micro- and nano-scale."

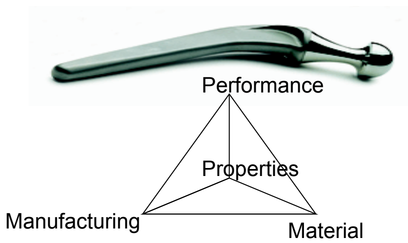
Flemings & Cahn

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…."

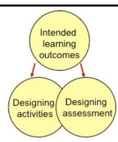
Östberg





[Professor Maria Knutson Wedel, Chalmers]

Example – a course in Materials Science

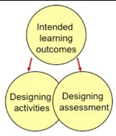


Implications I
- formulating intended learning outcomes

Old learning objectives (the disciplinary knowledge in itself)	New learning objectives (performances of understanding)
…describe crystal structures of some metals…	…select materials based on considerations for functionality and sustainability
…interpret phase diagrams…	…explain how to optimize material dependent processes (eg casting, forming, joining)
…explain hardening mechanisms…	…discuss challenges and trade-offs when (new) materials are developed
…describe heat treatments…	…devise how to minimise failure in service (corrosion, creep, fractured welds)

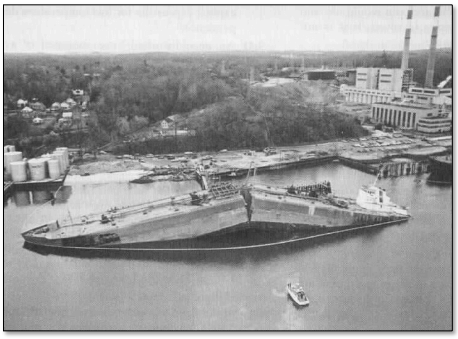
[Professor Maria Knutson Wedel, Chalmers]

Example – a course in Materials Science



Implications II
- design of learning activities

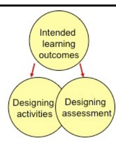
Still lectures and still the same book, but framed differently:
- from product to atoms
- focus on engineering problems



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]

Example – a course in Materials Science



Implications III
- design of assessment

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

[Professor Maria Knutson Wedel, Chalmers]

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CONCEIVE DESIGN IMPLEMENT OPERATE

Learning-driven Design of Project-Based Courses

Jakob Kuttenkeuler, jakob@kth.se
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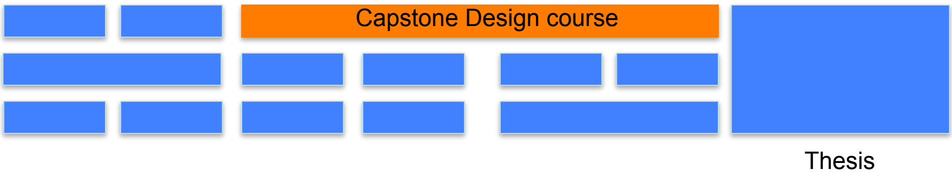
Kristina Edström, kristina@kth.se

One part of the solution

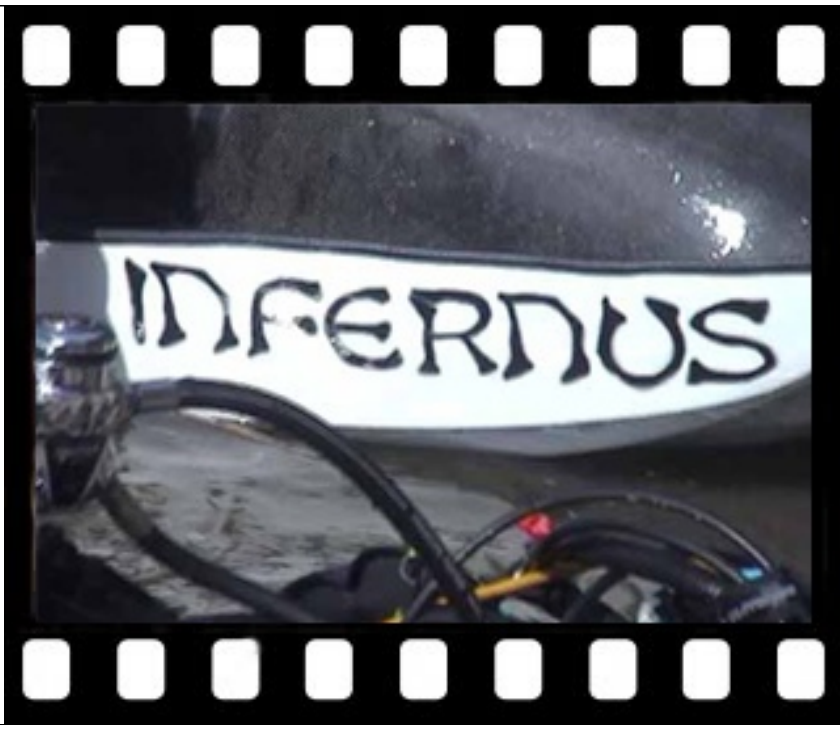
In a 2 year master program



- 2 semester course, 20 ECTS (one third of their time for a year)
- **Standard funding** (low material budget, teaching effort no more than any subject course)
- 8-15 students per project group – some 40 students in total
- A dedicated ”standard” classroom as home base (open 24/7)
- **Individual grading** A-F

First day

Conceive, design, build and operate –
a vehicle that can transport one person both in planing speed on the water surface as well as at low speed submerged



New projects every year...

...but always the same learning objectives

After the course the participant is expected to be able to:

- analyse technical problems in a **systems view**
- handle technical problems which are **incompletely stated** and subject to multiple constraints
- develop strategies for **systematic choice and use of available engineering methods and tools**
- **make estimations** and appreciate their value and limitations
- **make decisions** based on acquired knowledge
- **pursue** own ideas **and realise** them practically
- **assess quality of** own **work** and work by others
- work in a true **project setting** that effectively utilises available resources
- explain **mechanisms behind progress and difficulties** in projects
- **communicate engineering** – orally, in writing and graphically

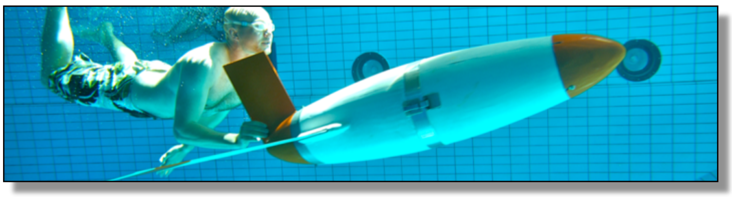
Students create new things

- Teachers advice & coach, but do not impose solutions
- Allow students to grow into engineers

- Conceive
- Design
- Implement
- Operate

- New year - New group - new task
- Neither students nor teachers know the answers

- Applied use of theoretical skills
- Whatever is designed has to be realised



The same learning outcomes can be reached through different activities

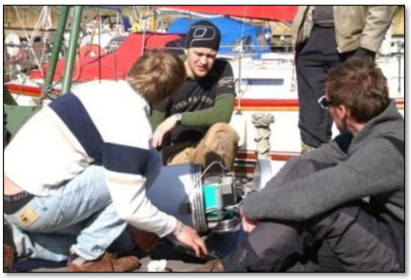
Students do different tasks in the project
a smörgåsbord syllabus for a smörgåsbord of students!

- Conceptual analysis
- "Expert" analysis
- Project management
- Manufacturing
- Presentations
- Experiments
- PR
- Planning and follow-up
- …

→ Students need to take individual responsibility for their learning outcomes

Assessment

- Individual grades (A-F)
- Assessing individual performance in a group setting
- Students work on many different tasks
- Teachers see only fragments of the actual performance (2 hours scheduled/week)
- Reliability / fairness



Assessment – the Introduction

Faculty

- communicate course goals
- instruct students to collect evidence in "portfolios"

Mid Course & Course End

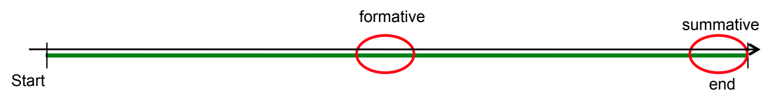
Faculty

- repeat course goals
- discussion on giving/receiving feedback

Students

- write summary
- read summaries, write feedback, suggest peer grades
- read feedback & reflect

- follow-up on the process



Summary: Sample (mid course)

- **L7. Effectively choose and use available engineering methods.**
  Status: Approaching. Ref: [4][5][6] ,
  - I am trying but find it hard to find the balance between rough estimates and sophisticated computerized methods. Further, the word "effectively" does not apply on me.
- **L10. Present technical work.**
  Status: Satisfied. Ref: [2] [4] [5] [6] [7],
  - I am author of 7 reports of which [2][5][6] as main author.
  - Prepared and given the presentation on the preliminary design [3] together with Jocke.

References (links to shared documents on project web site):

1. Meeting minutes from …
2. Presentation, Preliminary design at design review #1
3. Experiment 4, Planning, execution and results
4. Report A 12, Hydrostatic stability - analysis
5. Report A107, Engine, design and mounting

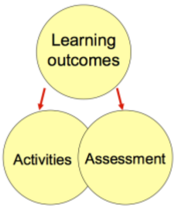
Grades are set by the teachers

The grades are set **in relation to the intended learning outcomes** based on a holistic assessment of:

- **portfolios** (reports, protocols, presentations, hardware, …)
- **given feedback**
- **received feedback**
- **recommended grades from peers**
- **participation, logged time and continuous observations**

by two teachers, independently

Why is the assessment system so complicated?



Powerful principle 1:
the purpose is student learning

Let's listen to some student voices

Interviews with students in the 2004 & 2005 cohorts
(not the students in the picture...)

Interviewer:
So you chose not to switch project leader?

"[Changing the project leader] wouldn't have furthered the project. It could only have suffered. But if you completely drop [considerations for] the product - and maybe you should, actually – it might have furthered the course. It's hard to tell...you simply tend to put your focus on the product you are making."

Tension between project and learning...

Interviewer: How do you think this course could be improved?

In the beginning I think there should have been some technical seminars to give a faster start of the project. Technical specialists who could have given a few lectures.

To help you see possible designs for instance?

Yes, technical solutions. And whom we could have contacted later with questions.

Hmm. I wonder if you may risk the main idea of the course?

Yes... that is a risk... If they say 'this is what you should do'... Yes, you are right.

But you think it would have been better with a more efficient start.

Yes, but that is perhaps because it had led to a better end result, I mean the boat. But maybe the learning wouldn't...

Tension between project and learning...
Conceptions of teacher's and student's roles are challenged...

Interviewer: How do you think this course could be improved?

They should have been more like teachers. We had to do all the hard work ourselves and we don't feel that we got as much help from the teachers as we could have had. [...] When we went and asked them 'does this look alright', they tried to answer as vaguely as they could. Just because they tried to make us solve things ourselves I think.

Student's views on knowledge are challenged...
Conceptions of teacher's and student's roles are challenged...

Student views must always be interpreted

- We notice that the teacher will often be blamed, as students think **they should have been saved** from the inconvenience.
- But these relevant challenges are not ”flaws” that should be eliminated. They are **key learning opportunities** and we have no intention to protect the students from them.
- It is then not appropriate to behave in conformity with student expectations. But knowing they existed was valuable for course development.

- **Conclusion:**
  Don't give the students what they want – give them something better!

Powerful principle 2:
Focus on process and individual

(then the group and the project will take care of themselves)

- Feedback is most effective for learning when it aims at students **work processes and self regulation**, rather than the task in itself.

  Hattie, J. & Timperley, H. (2007). The Power of Feedback. *Review of Educational Research*, 77(1), 81–112.

- **Individual** grading of learning outcomes because
  - Group/product grades are loosely coupled to learning outcomes
  - Group/product grades create conflict around differences in ambition level (takes much energy from students and teachers)
  - Product grades create incentives not to learn

Powerful principle 3: rub the students against each other

- The process is rich with peer feedback and self-reflection activities

  → **Good for learning**
  because experience results in learning only if reflected upon

  → **Good for teaching**
  because of the cost-effectiveness, faculty role is to create and run a **process for** generating feedback

Powerful principle 4: reversing the 'burden of proof'

- Each individual student is responsible for collecting and presenting evidence related to the learning outcomes (portfolio)

  → **Good for learning**
  because this **enhances reflection** and directs students attention to the intended learning outcomes (->*learning*)

  → **Good for teaching**
  because it makes the course format **sustainable**

Powerful principle 5: 'for the good of the project'

- The **project** and the **group** drives the specifications, the needs, the deadlines... not the teachers!

→ **Good for learning**
because this makes everything students do in the course **meaningful**, reporting has a function, meetings have a function…

→ **Good for teaching**
because it makes the course format **sustainable**

Powerful principle 1: the purpose is student learning

The purpose is not that students should solve this particular task, but that that they learn the skills to make 100 such projects in their career…

Powerful principle 1: the purpose is student learning

TRADEOFFS:

- NOT reaching project goals (BUT the project still drives learning and creates a motivational context)
- NOT technical sophistication (BUT the projects must still accommodate these learning outcomes)
- NOT student satisfaction (BUT the motivational context must work)
- NOT teacher popularity (BUT the students must still have trust in the process and the teachers)

The beautiful sound of students growing into engineers... (I)

The greatest thing I have learned from this course is humility. I'll approach similar tasks more humbly in the future. We thought we were better than we were. No, not better, but we have taken courses with well-defined problems, where there is an answer, the key. And that went well. But now you realised that as soon as you are confronted with reality, it's quite another story.

The beautiful sound of students growing into engineers... (II)

”It took some time (maybe even a month) before it felt like we really got started. We were fumbling around, doing tasks without really completing them or seeing what was the conclusion, the next step from it. We wrote reports and said ‘we do this for our own sake’ but it took some time before that was actually the case. At least that’s how it was for me. But when that coin dropped, everything became very much easier.”

...and more of the same...

“At the beginning of the course I was somewhat worried about finishing the education and starting to work as an engineer. Those worries are gone now. My confidence in approaching technical problems and solving them has grown a lot.”

“Feedback was exchanged on everything between napkin scribbles at lunch to things you had built. This was valuable since it both gave me, and trained me to give, critique. It also helped me to see how other people are thinking and how they solve problems.”

“One of the best things during the project was that written documentation was called for and that we in much lived up to those demands. It allows you to cross check things and check the work of yourself and others, and things are always available.”

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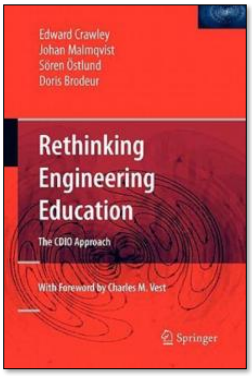
-- Edström, Campbell and Hallström (2011). *Learning and Assessment in Project-Based Learning Courses Around the World* (workshop), Frontiers in Education, Rapid City, South Dakota.

What is CDIO?

A method/approach

- What? **CDIO Syllabus** (2001)
- How? **CDIO Standards** (2006)
- Crawley et al (2007) *Rethinking Engineering Education: The CDIO Approach*, Springer (1st ed)



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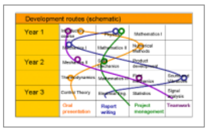
CDIO curriculum development - the process in a nutshell

- **Set program learning outcomes**
  in dialogue with stakeholders



- **Design integrated curriculum**
  by mapping out responsibilities to courses
  – negotiate intended learning outcomes for courses
  (knowledge <u>and</u> engineering skills)

- **Create integrated learning experiences**
  by 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?

<u>A community</u>

- The **CDIO Initiative** was founded in 2000 by MIT, KTH, Chalmers, Linköping University
  - Support from the Knut & Alice Wallenberg foundation (2001-2005)
- 1st annual **CDIO Conference** in 2005
- Today over 90 **CDIO Collaborators** worldwide

9th international CDIO conference
9-13 juni 2013, MIT/Harvard, Cambridge, MA
www.cdio2013.org

CDIO Collaborators

North America:
- U. S. Naval Academy
- Massachusetts Institute of Technology
- 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

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 ScienceReykjavik University
- 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
- **Skolkovo Institute of Science and Technology**
- **Tomsk Polytechnic University**
- **Astrakhan State University**
- Vilniaus Kolegija/University of Applied Sciences

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
- 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

Success is not inherent in a method; it always depends on good implementation of it.