



Putting the Learning Back Into Project-based Learning

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Design-Implement Experiences

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

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.

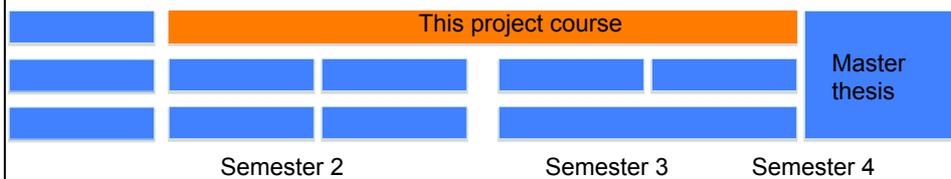
**First day of the course,
each group of 8-16 students get a challenge:**

e.g.

Conceive, design, build and operate
a vehicle that can transport one person
at planing speed on water
and at low speed submerged.

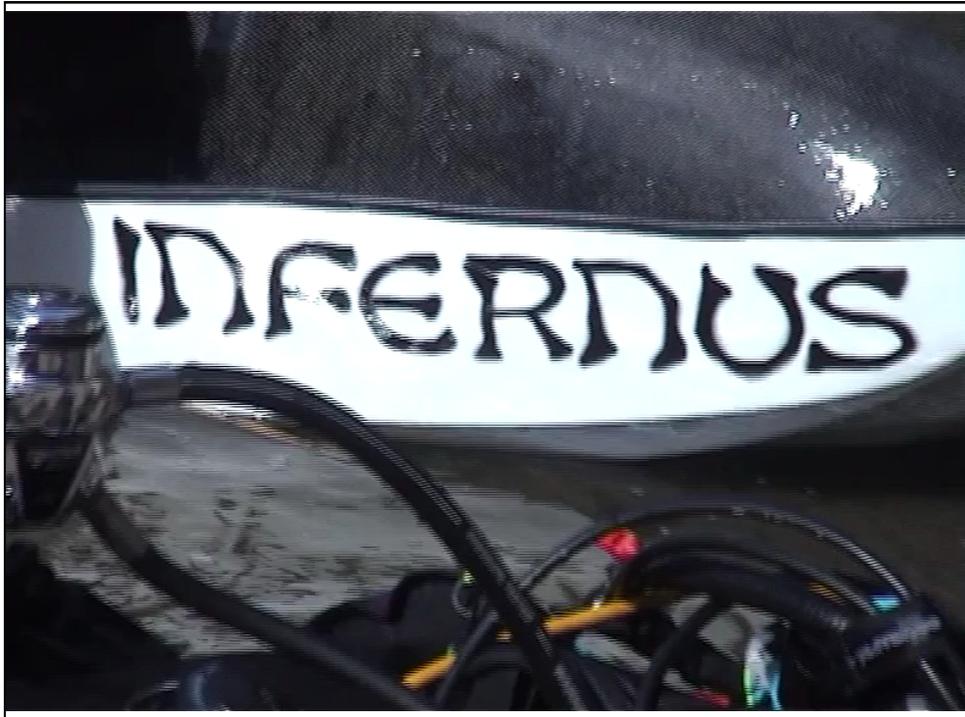


Some facts about the course



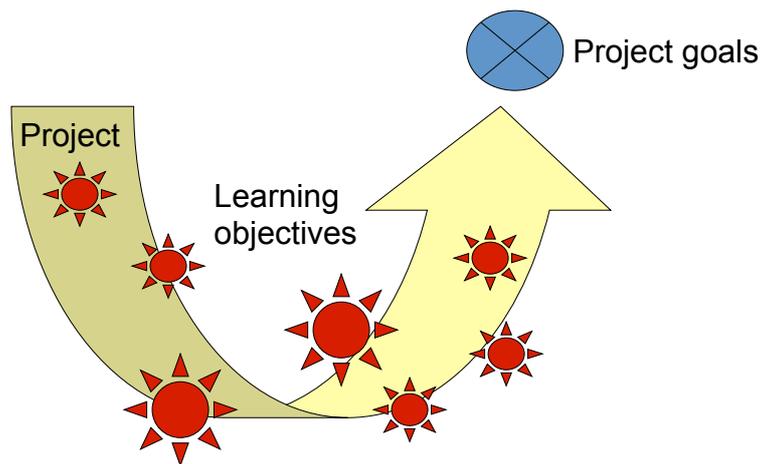
- Class of 30-40 students from mixed programs, groups of 8-16,
- 2 semesters, 20 ECTS (1/3 of students' time for a year)
- Individual grading A-F

- 2 weekly scheduled hours but most activities “on demand”
- Standard course funding (low material budget, limited teaching time)
- Access to a standard classroom “owned” by the students (24/7)
- Access to department workshops



So clearly the students had fun but:

Why do we have project-based courses?



**The purpose is not to make things;
it is to learn from making things.**

Powerful principle #1

The purpose is student learning



**The projects look different every year...
...but the learning objectives are the same!**



After the course the participant should be able to:

- take on technical problems with a **systems view**



We want the students to focus on:

What are actually the challenges and keys to success?

What are the important questions/issues/tasks?

How does *my contribution* fit into the bigger picture?

All the interfaces...

How to cooperate, manage and drive the project...

...

After the course the participant should be able to:

- take on technical problems in a systems view
- handle technical problems which are **incompletely stated** and subject to multiple constraints



Project organization
(Easier said than done)



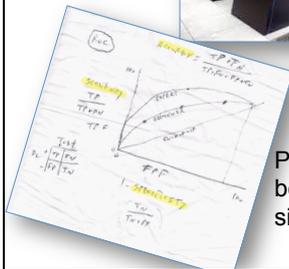
The project management subdivides the work

- who will "look at" propulsion?

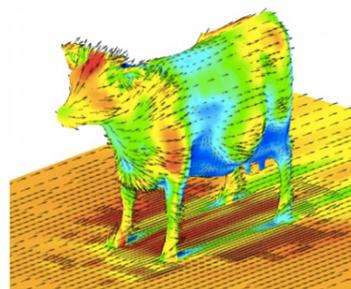
After the course the participant should be able to:

- take on technical problems in a **systems view**
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- **develop strategies for systematic choice and use of available engineering methods and tools**

The natural first choice



Power and beauty of initial simple models



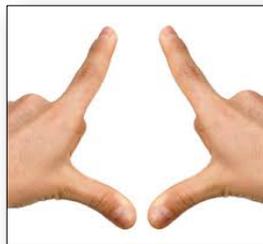
Focusing on what matters

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- 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



Everyone is always waiting for better input!



Correctly used, estimations are gold



Remember to revisit and challenge

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- **make estimations** and appreciate their value and limitations
- **make decisions** based on acquired knowledge



Comfort zone



This is scary

How does the project make decisions?



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- 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



- To discuss, argue, debate and stand up for your standpoint.
- Sometimes let go of darlings.



Struggle with real world issues, e.g. play, friction, misalignment...



Testable state where my effort made a difference

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- **assess quality of own work** and work by others

More on this when we talk about assessment.

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- work in a true **project setting** that effectively utilises available resources

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- work in a true project setting that effectively utilises available resources
- **explain mechanisms behind progress and difficulties** in such a setting



Big groups (8-16)

Deadlines
Professionalism
Decision making
Keeping people busy
Traceability in decisions
Group contract

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- **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 such a setting
- **communicate engineering** – orally, in writing and graphically

All possible modes of communication in authentic situations!

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The purpose is learning

Given the nature of the learning objectives, students must be exposed to:

- The logic of problems (rather than discipline)
- Empowerment and responsibility
- Open-ended problems
- Validation rather than “right answers”
- Principles and concepts “in the wild”



Our students struggle when accidentally stumbling on fundamental principles and concepts “in the wild”

Newton's laws
Ohms law
Archimedes principle
Equilibrium and stability
Equations of motion
Feedback control
etc

Powerful principle #2

The project sets the logic



- **The project** sets the logic and drives specifications, plans, needs, deadlines... **not the teachers!**

- This makes everything students do in the course **meaningful**, reporting comes natural (for the first time).
- This makes the course format **sustainable**

Powerful principle #3

The students own the project



- **Teachers advise and coach**, but do not provide solutions. Students are not protected from mistakes, friction or anxiety. The project results will reflect the students' level of proficiency, not the teachers'.

- This allows, and forces, students to think for themselves, growing into engineers
- This makes the course format **sustainable**

Maria Montessori:

EVERY TIME YOU TIE THE SHOES FOR YOUR CHILD, YOU HINDER HER OWN DEVELOPMENT.



The purpose is learning – but how to assess it individually in a group environment?

Grading is individual towards the learning objectives

The **group product is not graded**, because it is aggregated and loosely coupled to learning

- **Group grades are unfair** as they don't necessarily reflect one's own achievements.
- **Group grades invite free riders** and **make low achievers a burden** to the group. This **generates conflicts** around ambition levels, taking focus from the work and learning.
- **Product grades (or end reports) are loosely coupled to learning outcomes.**
- **Product grades gives little incentive to learn**, but rather to specialise on what they already do well.

The set of learning outcomes can be reached through different activities

Students do many different tasks in the project

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



- We require students to take individual responsibility for reaching all learning outcomes.
- Therefore students will choose to engage in a variety of activities in order to reach all learning outcomes. This happens **automagically**.

Assessment challenges

- 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
- Legal security / fairness



Assessment

Faculty

- communicate course goals

Students

- plan their activities
- collect evidence of their progress towards the learning outcomes in individual “portfolios”



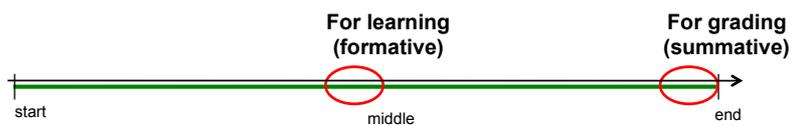
Assessment

Faculty

- repeat course goals
- lead discussion on giving/receiving feedback

Students

- write summary
- read all summaries in their group
- write feedback and suggest peer grades
- read feedback & reflect
- de-briefing



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.

L5. Make estimations, appreciating their value and limitations

The propeller analysis required several estimations during its initial phase, e.g. the input power from the solar cells to the engine and the hull resistance. When working with the supporting structure for the hulls [72] the design loads acting on the craft were also approximated based on evaluation of the most critical loading conditions. These estimations were made in order to operate with some numbers and start the calculations. It was understood that having some, even rough, estimations will not let the process stop and will have only positive influence on the overall result.

References:

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

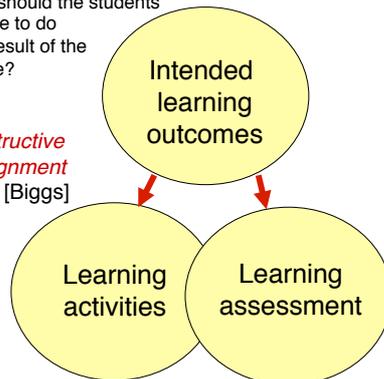
Grading criteria (agreed by the students for their use)

- For grade **A** you should also
 - Distinguish yourself in several of the above task areas and learning outcomes
 - Show special personal engagement, responsibility and initiative for the project and group work
- For grade **B** you should also
 - Work actively with analysis, practical implementation, administration and communication
 - Clearly show that you reached the learning outcomes
- For grade **C** you should also
 - Work in most of the fields analysis, practical implementation, administration and communication
 - Clearly show personal initiative and engagement in the course
- For grade **D** you should also
 - Work with several types of tasks in the project
 - To some extent take on responsibilities in the course
 - Clearly show that you approach most of the intended learning outcomes
- For grade **E** you should
 - Actively participate in the course seminars and project meetings
 - Actively participate in the course activities, read and answered emails from course leaders and delivered the course assignments
 - Spend time on task corresponding to 20 credits
 - Show that you approach the intended learning outcomes to a significant extent

Why is the assessment system so complicated?

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?

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



Powerful principle #4

Generating reflection on experience



- The course provides a firm structure for reflection, stimulated by feedback.
 - 'Learning by doing' – but doing is not sufficient for learning. **Reflection** is what **turns experience into learning**.
 - Teachers drive a process for rubbing students against each other. Faculty role is to **create and run the process** – not to give all the feedback. Note the cost-effectiveness.

How the grades are set

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

- **portfolios** (summary + references, e.g. reports, protocols, presentations, sketches, hardware, ...)
- **given feedback**
- **received feedback**
- **recommended grades from peers**

- **Participation, logged time and continuous observations**

by two teachers, independently

We do it in consensus ;-)



Powerful principle #5

Reversing the 'burden of proof'



- Each individual student is responsible for collecting and presenting evidence of their learning outcomes (in a portfolio)
 - this generates reflection and directs students attention to the intended learning outcomes
 - makes the course format **sustainable**

Key challenges – Let's hear 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?

“No, it 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.

I can see that it's been painful though.

Yes, but maybe that's what is good for us.

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...

Quote from a mid-course evaluation

Not that these were the only calculations needed, but the only ones that could be made. All the calculations assuming kinematic equilibrium seem to give various degrees of unreasonable results. This is not just a pity and shame, but it is also terribly bad pedagogy now towards the end of an education. I would really have liked to see that the theory we have learnt was possible to use. We cannot even calculate the strength since everything is so tiny.

Students with a black-and-white view on knowledge are seriously challenged...

Student views must always be interpreted

- We notice that
 - students' **conceptions of learning** or **attitude towards knowledge** is challenged
 - in students' eyes, **learning is often overshadowed** by the project per se
- 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 #1 revisited

The purpose is student learning



- **NOT reaching project goals**
(BUT the project still drives learning and creates a motivational context)
- **NOT technical sophistication**
(BUT there must be enough complexity and technical challenges to accommodate the learning outcomes)
- **NOT teacher popularity, or giving students what they want**
(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."

Frequently asked questions, or comments

	1	2	3
A	<ul style="list-style-type: none"> What would my chemical engineering (etc) students build? 	<ul style="list-style-type: none"> Why don't you run proper projects, like real boats instead of toys? 	<ul style="list-style-type: none"> What about the project budget?
B	<ul style="list-style-type: none"> Why not use competitions and/or industry as costumer? 	<p>Your questions and comments</p>	<ul style="list-style-type: none"> What can be done in earlier and smaller courses?
C	<ul style="list-style-type: none"> What about parallel courses? 	<ul style="list-style-type: none"> How do you come up with new project ideas every year? 	<ul style="list-style-type: none"> Should future PhD-students have to waste credits on this course?

The chair of a chemical engineering program asks

"What would our students build – a molecule, or what?"



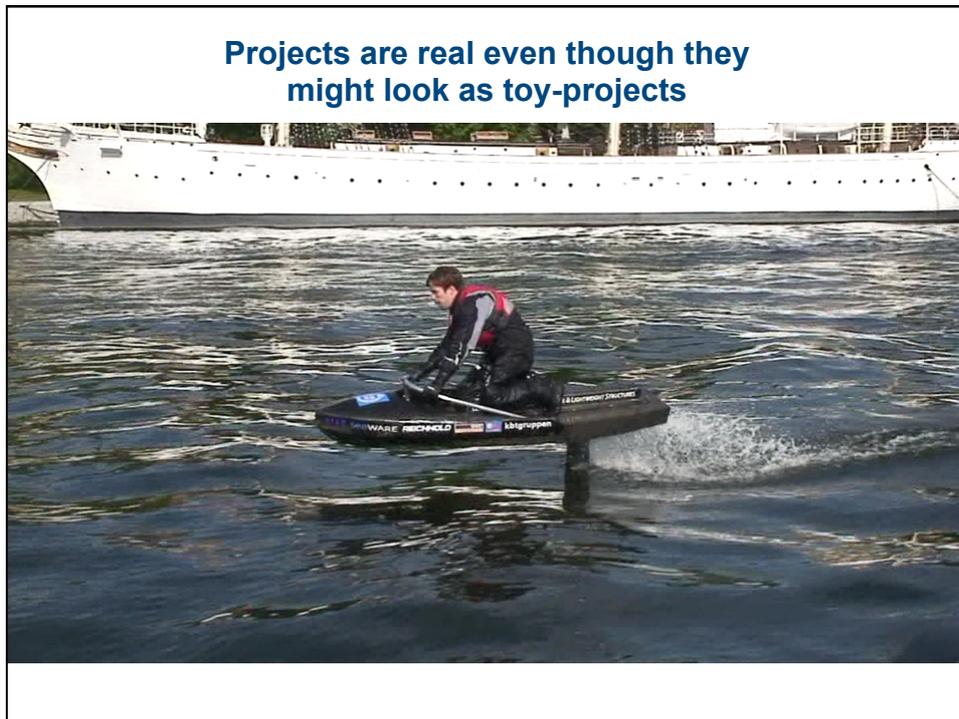
- The essential aim is to learn through near-authentic engineering tasks, working in modes resembling professional practice
- Projects take different forms in various engineering fields
- Think of what engineers do in your field (don't translate the artefact, consider the learning objectives)

**Actually we do have an example
from chemical engineering (1st year)**



Why don't you run a "proper project", why do you keep playing with the students in "toy-like" projects?





Makes students attractive!

Betsy Pfeiffer

i förrgår 23:08

BP

To: Jakob Kутtenkeuler, Stefan Hallström Cc: Don Montague
Evolu

Hello Professors Kутtenkeuler and Hallström,

I work for a small water sports R&D company in California that's been developing a kite-powered hydrofoil boat for several years. Lately, we have been working on an electric-powered hydrofoil surfboard, the Jetfoiler (videos here: <https://youtu.be/fhHEefqSepI> and here: <https://youtu.be/axgIVFKuAQ>).

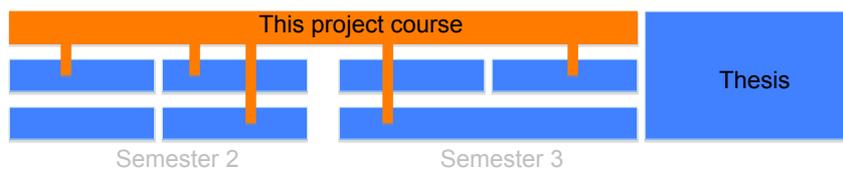
We recently found your Evolu videos online, and it looks like we're working on something similar. I'm wondering if you or any of your former students would be interested in talking to us or potentially advising us on future developments of the Jetfoiler.

Thank you for your time,
Betsy

Another relevant “toy-like project”



The Relation to Other Courses



Ok, tell us which of these learning objectives are irrelevant for preparing PhD students? ■

- 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 such a setting
- **communicate engineering** – orally, in writing and graphically

What can be done in earlier and smaller courses? ■

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

What about the project budget?

- We give each group \approx €2000 per project
- Students “hunt” sponsoring very effectively
(This is actually a part of the course)
- **Bigger budget does not obviously lead to better learning**

Why not use competitions and/or industry as customer?

These may be very good ideas! However, there are risks...

- **Trying to beat records** often lead to highly optimized, delicate and “risky” solutions that realistically need several iterations to work properly. This takes time - which we do not have in a course. 
- **Competitions** sometimes impose constraints that interfere with learning objectives. Collaborating parallel teams with same objectives has worked surprisingly well ☺
(In competitions, most contenders actually loose!) 
- **Industry costumers** are often valuable faculty relations that we do not want to disappoint. Thus, both students and faculty may feel a pressure to sacrifice learning just to “deliver”. Realistically... research level results should not be expected in a course like this.
- **Student engagement** does not seem to rely on competitions, records and/or industry costumers – which is actually extremely good news!

How do you come up with new project ideas every year? ■

There is no scientific way... but:

- **Faculty only need to come up with a “one-liner”** framing the big picture. Then, let the students take lead in forming the detailed spec which is iterated with faculty.
- **Key words:**
 - **Inspiring** challenge
 - **Relevant** technical challenges
 - **Realistic** goals with respect to time & money budgets
- Be creative over **a beer with faculty colleagues** 😊
- Why not engage students also in this phase?!

REFERENCES

- Edström, El Gaidi, Hallström and Kutteneuler (2005). Integrated assessment of disciplinary, personal and interpersonal skills - student perceptions of a novel learning experience, *Proceedings of the 13th Improving Student Learning*, OCSLD, Oxford, UK.
- Hallström, Kutteneuler and Edström (2007). The route towards a sustainable design-implement course, *Proceedings of the 3rd CDIO Conference*, Cambridge, MA.