A CDIO Review:
Engineering Education for the 21^{st} century

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CHALLENGES AND OPPORTUNITIES FOR ENGINEERING EDUCATION

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Problems

- Multi-disciplinary problems
- Globaliz-ation
- New technologies & services
- Sustain-able solutions
- Entre-preneurship

Skills

- Design & Innovation
- Communication & teamwork
- Personal skills

Constraints & resources

- Prior knowledge
- Faculty competence & time
- Digital tools and learning

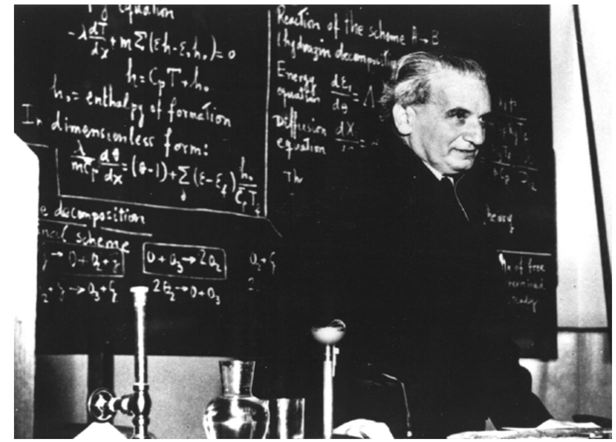
- **Remarkable similarity across the world!**
- **Opportunity: Through use of pedagogical innovation and worldwide collaboration, educate engineers who can develop a better future**

OUTLINE

- **What is an engineer? What is the professional context of engineering?**
- **The need for a new approach**
  - **The CDIO goals and vision**
  - **What do engineering graduates need to be able to do?**
  - **How can we do better at educating them?**
- **Concluding remarks & discussion**

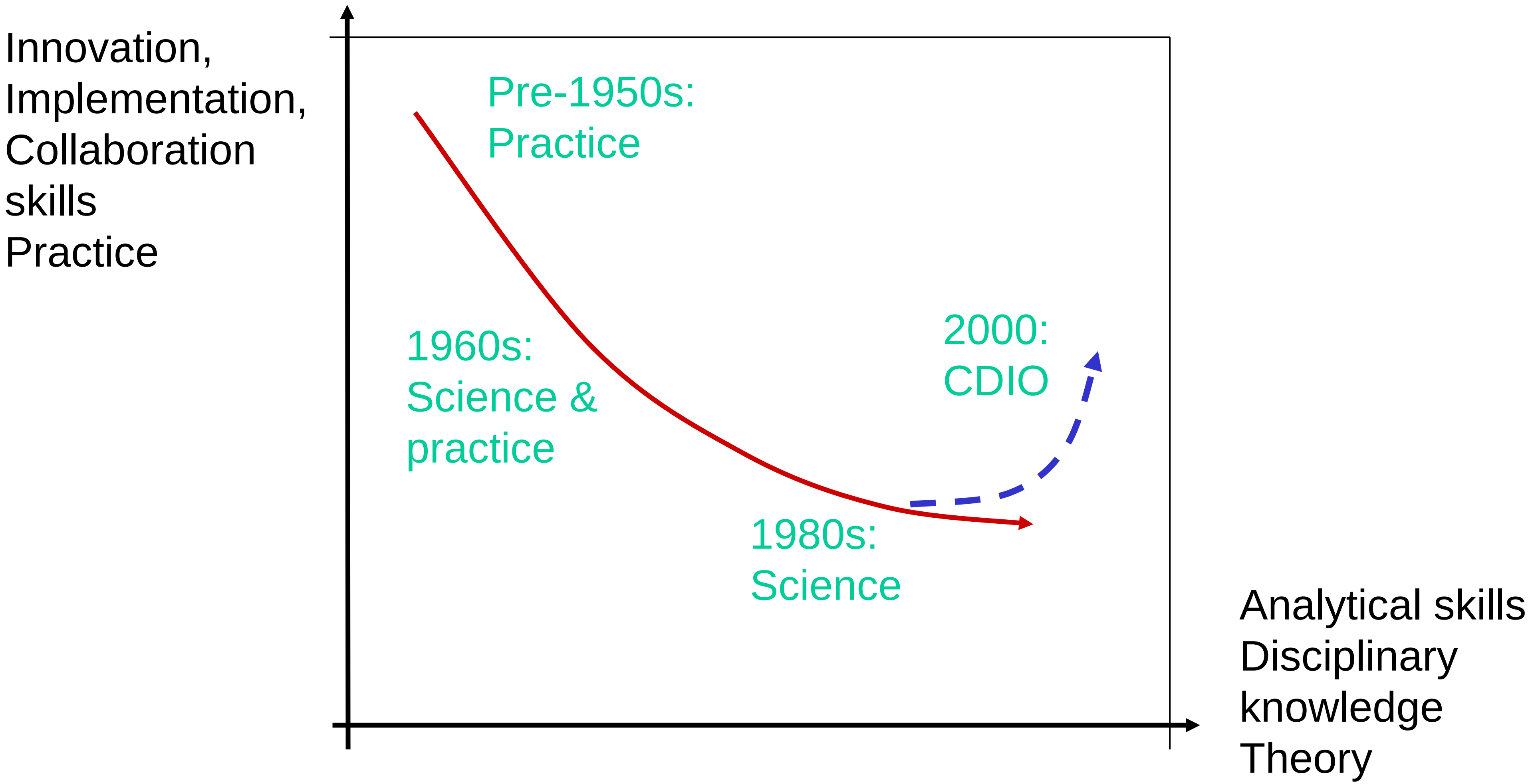
WHAT DO ENGINEERS DO?

**”Scientists investigate that which already is.
Engineers <u>create</u> that which has never been.
- Theodore von Karmann**



**”What you need to invent, is an imagination and a pile of junk”
- Thomas Edison**

EVOLUTION OF ENGINEERING EDUCATION



We are not where we want to be –
engineering education needs reform!

REFORM OF ENGINEERING EDUCATION IS NEEDED - WITH THREE MAIN GOALS IN MIND

To educate students who are able to:

- **Master a deeper working knowledge of the technical fundamentals**
- **Lead in the creation and operation of new products, processes, and systems**
- **Understand the importance and strategic impact of research and technological development on society**

CENTRAL QUESTIONS FOR PROFESSIONAL EDUCATION DESIGNERS

- **What is the professional role and practical context of the profession(al)? (need)**

- **What knowledge, skills and attitudes should students possess as they graduate from our programs? (program learning outcomes)**

- **How can we do better at ensuring that students learn these skills? (curriculum, teaching, learning, workspaces, assessment)**

Massachusetts Institute of Technology

THE PROFESSIONAL ROLE(S) OF ENGINEERS

”Engineers <u>Conceive</u>, <u>Design</u>, <u>Implement</u> and <u>Operate</u> complex products and systems in a modern team-based engineering environment”

CONTEXT FOR ENGINEERING: THE C-D-I-O PROCESS

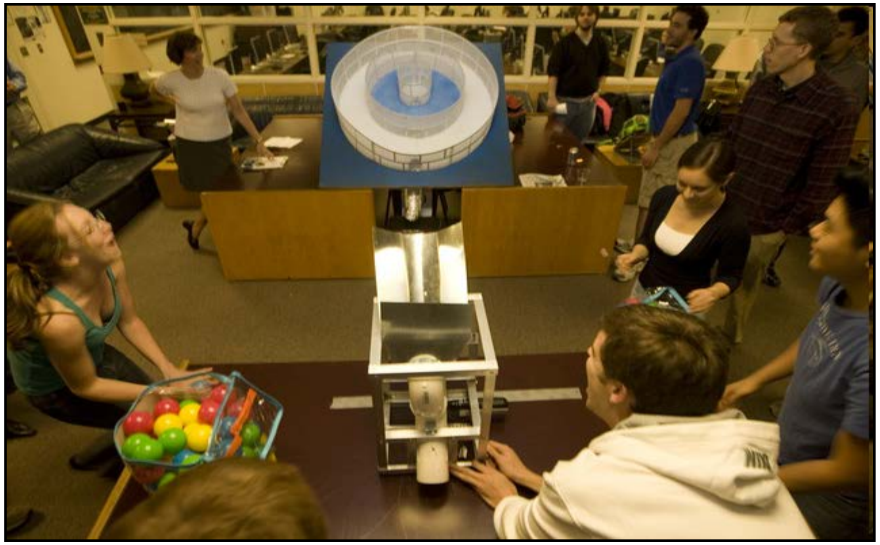
Lifecycle of a product, process, project, system, software, material

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



Duke University

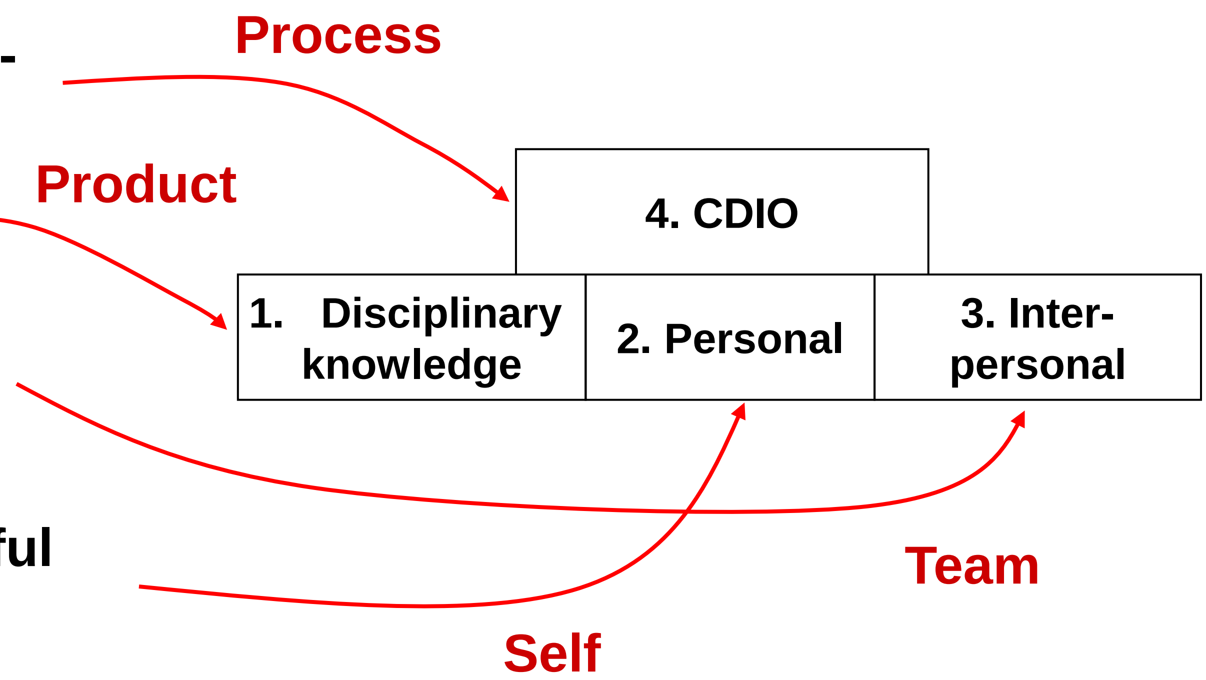
What is the full set of knowledge, skills and attitudes that a student should possess as they graduate from university?

- **At what level of proficiency?**
- **In addition to the traditional engineering disciplinary knowledge**

FROM UNDERLYING NEED TO PROGRAM LEARNING OUTCOMES

Educate students who:

- **Understand how to conceive-design-implement-operate**
- **Complex products and systems**
- **In a modern team-based engineering environment**
- **And are mature and thoughtful individuals**



The CDIO Syllabus - a comprehensive statement of detailed <u>goals for an engineering education</u>

THE CDIO SYLLABUS

- **A generalized list of competences that an engineer should possess**
- **Program specific (1) and general (2-4)**
- **Created and validated by alumni, faculty and students**
- **A "complete" reference model**

1 Disciplinary Knowledge & Reasoning:
1.1 Knowledge of underlying sciences
1.2 Core engineering fundamental knowledge
1.3 Advanced engineering fundamental knowledge

2 Personal and Professional Skills
2.1 Analytical reasoning and problem solving
2.2 Experimentation and knowledge discovery
2.3 System thinking
2.4 Personal skills and attributes
2.5 Professional skills and attributes

3 Interpersonal Skills
3.1 Multi-disciplinary teamwork
3.2 Communications
3.3 Communication in a foreign language

4 CDIO of Complex Systems
4.1 External and societal context
4.2 Enterprise and business context
4.3 Conceiving and engineering systems
4.4 Designing
4.5 Implementing
4.6 Operating
4.7 Engineer leadership
4.8 Entrepreneurship

CDIO Syllabus contains 2-3 more layers of detail

THE CDIO SYLLABUS V2.0 - 3RD LEVEL OF DETAIL (EXCERPT)

1 DISCIPLINARY KNOWLEDGE AND REASONING

1.1 KNOWLEDGE OF UNDERLYING MATHEMATICS AND SCIENCES
1.2 CORE ENGINEERING FUNDAMENTAL KNOWLEDGE
1.3 ADVANCED ENGINEERING FUNDAMENTAL KNOWLEDGE, METHODS AND TOOLS

2 PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES

2.1 ANALYTICAL REASONING AND PROBLEM SOLVING
- 2.1.1 Problem Identification and Formulation
- 2.1.2 Modeling
- 2.1.3 Estimation and Qualitative Analysis
- 2.1.4 Analysis With Uncertainty
- 2.1.5 Solution and Recommendation

2.2 EXPERIMENTATION, INVESTIGATION AND KNOWLEDGE DISCOVERY
- 2.2.1 Hypothesis Formulation
- 2.2.2 Survey of Print and Electronic Literature
- 2.2.3 Experimental Inquiry
- 2.2.4 Hypothesis Test and Defense

2.3 SYSTEM THINKING
- 2.3.1 Thinking Holistically
- 2.3.2 Emergence and Interactions in Systems
- 2.3.3 Prioritization and Focus
- 2.3.4 Trade-offs, Judgment and Balance in Resolution

2.4 ATTITUDES, THOUGHT AND LEARNING
- 2.4.1 Initiative and the Willingness to Make Decisions in the Face of Uncertainty
- 2.4.2 Perseverance, Urgency and Will to Deliver, Resourcefulness and Flexibility
- 2.4.3 Creative Thinking
- 2.4.4 Critical Thinking
- 2.4.5 Self-awareness, Metacognition and Knowledge Integration
- 2.4.6 Lifelong Learning and Educating
- 2.4.7 Time and Resource Management

2.5 ETHICS, EQUITY AND OTHER RESPONSIBILITIES
- 2.5.1 Ethics, Integrity and Social Responsibility
- 2.5.2 Professional Behavior
- 2.5.3 Proactive Vision and Intention in Life
- 2.5.4 Staying Current on the World of Engineering
- 2.5.5 Equity and Diversity
- 2.5.6 Trust and Loyalty

3 INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION

3.1 TEAMWORK
- 3.1.1 Forming Effective Teams
- 3.1.2 Team Operation
- 3.1.3 Team Growth and Evolution
- 3.1.4 Team Leadership
- 3.1.5 Technical and Multidisciplinary Teaming

3.2 COMMUNICATIONS
- 3.2.1 Communications Strategy
- 3.2.2 Communications Structure
- 3.2.3 Written Communication
- 3.2.4 Electronic/Multimedia Communication
- 3.2.5 Graphical Communication
- 3.2.6 Oral Presentation
- 3.2.7 Inquiry, Listening and Dialog
- 3.2.8 Negotiation, Compromise and Conflict Resolution
- 3.2.9 Advocacy
- 3.2.10 Establishing Diverse Connections and Networking

3.3 COMMUNICATIONS IN FOREIGN LANGUAGES
- 3.3.1 Communications in English
- 3.3.2 Communications in Languages of Regional Nations
- 3.3.3 Communications in Other Languages

VALIDATION OF THE CDIO SYLLABUS: STAKEHOLDER SURVEY AT MIT

Sample: 6 groups surveyed: 1st- and 4th-year students, alumni 25 years old, alumni 35 years old, faculty, leaders of industry

Question: For each attribute, please indicate which of the five levels of proficiency you desire in a graduating engineering student:

Scale:

1 To have experienced or been <u>exposed</u> to

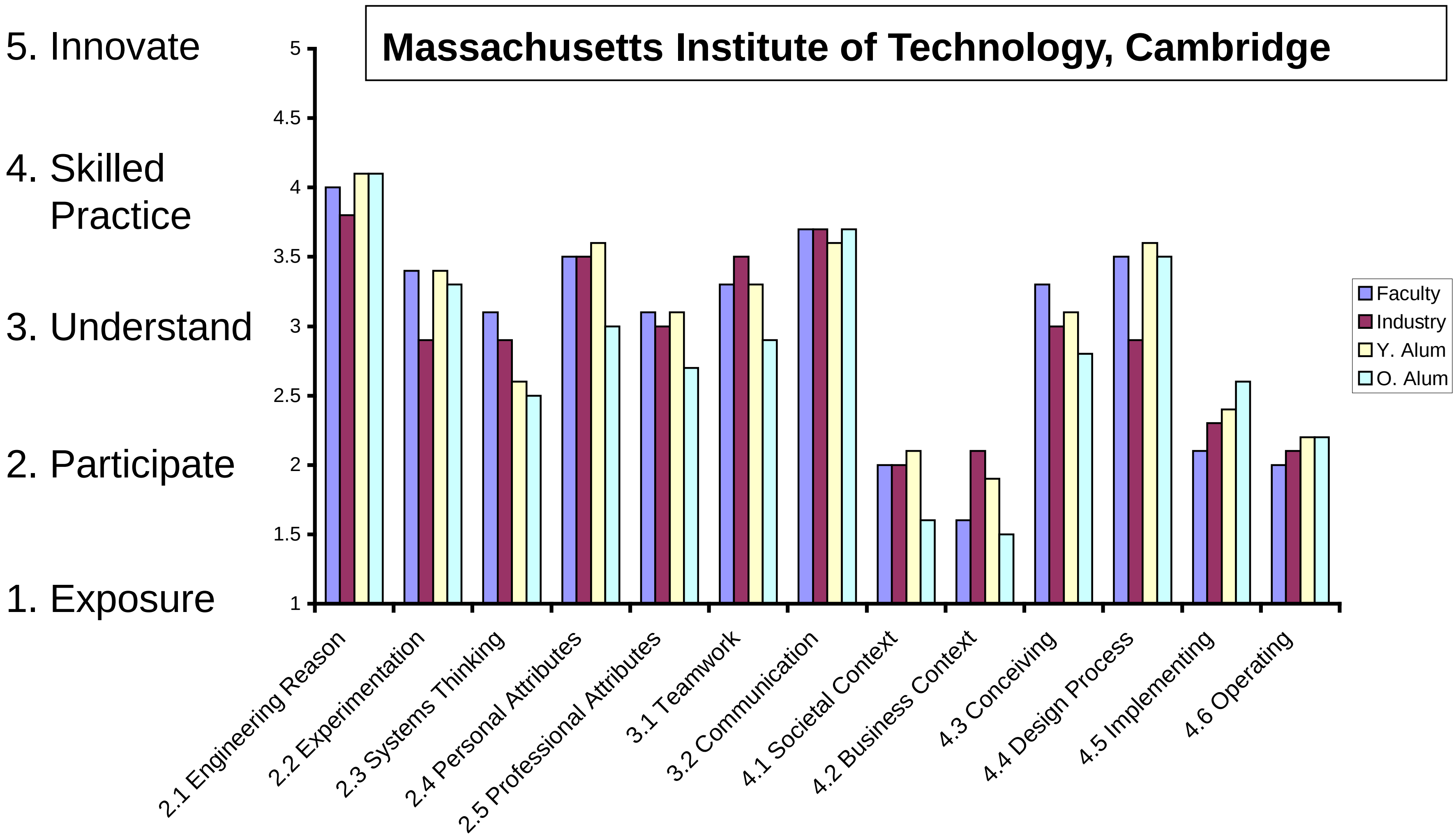
2 To be able to <u>participate</u> in and contribute to

3 To be able to <u>understand</u> and explain

4 To be <u>skilled in the practice</u> or implementation of

5 To be able to lead or <u>innovate</u> in

PRIORITING LEARNING OUTCOMES



Analysis is rated highest but almost as high proficiency is needed in design, communication and teamwork

VALIDATION AGAINST NATIONAL ACCREDITATION FRAMEWORKS

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- **The CDIO syllabus has been compared national accreditations in many countries**
- **Same pattern:**
  - **The CDIO Syllabus states outcomes for engineering education that reflect a broader view of the engineering profession**
  - **Its greater levels of detail facilitate program and course development.**
  - **A program whose design is based on the CDIO Syllabus will also satisfy its national requirements for specified program outcomes.**

ABET EC 2010 (USA)

CDIO Syllabus	ABET EC2010 Criterion 3										
	a	b	c	d	e	f	g	h	i	j	k
1.1 Knowledge of Underlying Mathematics, Science	■										
1.2 Core Engineering Fundamental Knowledge	■										
1.3 Adv. Engr. Fund. Knowledge, Methods, Tools	▒										■
2.1 Analytical Reasoning and Problem Solving					■						▒
2.2 Exper., Investigation and Knowledge Discovery		■									
2.3 System Thinking			▒								
2.4 Attitudes, Thought and Learning									■		
2.5 Ethics, Equity and Other Responsibilities						■					▒
3.1 Teamwork				■							
3.2 Communications							■				
3.3 Communication in Foreign Languages											
4.1 External, Societal and Environmental Context			▒					■		■	
4.2 Enterprise and Business Context			▒					■			
4.3 Conceiving, Systems Engr. and Management			■								
4.4 Designing			■								
4.5 Implementing			▒								
4.6 Operating			▒								
	■ Strong Correlation					▒ Good Correlation					

CEAB (CANADA)

CDIO Syllabus	CEAB Graduate Attributes Criteria 3.1											
	1	2	3	4	5	6	7	8	9	10	11	12
1.1 Knowledge of Underlying Mathematics, Science	■											
1.2 Core Engineering Fundamental Knowledge	■											
1.3 Advanced Eng. Fundamental Knowledge, Methods, Tools	▒				■							
2.1 Analytical Reasoning and Problem Solving		■									▒	
2.2 Experimentation, Investigation and Knowledge Discovery			■				▒					
2.3 System Thinking												
2.4 Attitudes, Thought and Learning		■	■	■	■							■
2.5 Ethics, Equity and Other Responsibilities								■		■		▒
3.1 Teamwork						■						
3.2 Communications							■					
3.3 Communication in Foreign Languages												
4.1 External, Societal and Environmental Context								■	■			
4.2 Enterprise and Business Context											■	
4.3 Conceiving, Systems Engineering and Management				■					▒		▒	
4.4 Designing				■								
4.5 Implementing												
4.6 Operating				▒								
	■ Strong Correlation						▒ Good Correlation					

EUR-ACE (Europe)

EUR-ACE syllabus, 2nd cycle	CDIO syllabus level x.x																
	1.1	1.2	1.3	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	4.1	4.2	4.3	4.4	4.5	4.6
1.1	x																
1.2		x															
1.3			x														
1.4						x									x		
2.1				x													
2.2				x										x	x		
2.3				x										x	x		
2.4			x	x										x	x		
3.1														x	x		
3.2							x							x	x		
3.3						x								x	x		
4.1					x												
4.2					x												
4.3					x												
4.4			x		x												
5.1		x	x	x													
5.2		x	x	x		x											
5.3		x	x	x													
5.4												x	x				
6.1									x								
6.2										x							
6.3								x				x					
6.4													x				
6.5							x										
6.6									x					x			

COMPARISON WITH INDUSTRY EXPECTATIONS - DESIRED ATTRIBUTES OF AN ENGINEER (BOEING, CA 1995)

- A good understanding of engineering science fundamentals
  - Mathematics, Physical and life sciences, Information technology
- A good understanding of design and manufacturing processes
- A multi-disciplinary, systems perspective
- A basic understanding of the context in which engineering is practiced
  - Economics, History, The environment, Customer and societal needs
- Good communication skills - written, oral, graphic, and listening
- A profound understanding of the importance of teamwork.
- Personal skills
  - High ethical standards
  - Ability to think both critically and creatively—independently and cooperatively
  - Flexibility
- Curiosity and a desire to learn for life

How can we do better at assuring that students learn these skills?

– ***Within the available student and faculty time, funding and other resources***

VISION FOR A CDIO-BASED EDUCATION

An education that stresses the fundamentals, set in the context of Conceiving – Designing – Implementing – Operating systems and products:

- **A curriculum organised around mutually supporting courses, but with CDIO activities highly interwoven**
- **Rich with student design-build projects**
- **Integrating learning of professional skills such as teamwork and communication**
- **Featuring active and experiential learning**
- **Constantly improved through quality assurance process with higher aims than accreditation**

MORE AND MORE AUTHENTIC DESIGN EXPERIENCES IN THE EDUCATION

Design-build experiences are instructional events in which learning occurs through the creation of a <u>product</u>, <u>process</u>, or <u>system</u>

Provide the natural context in which to teach design, innovation, implementation skills

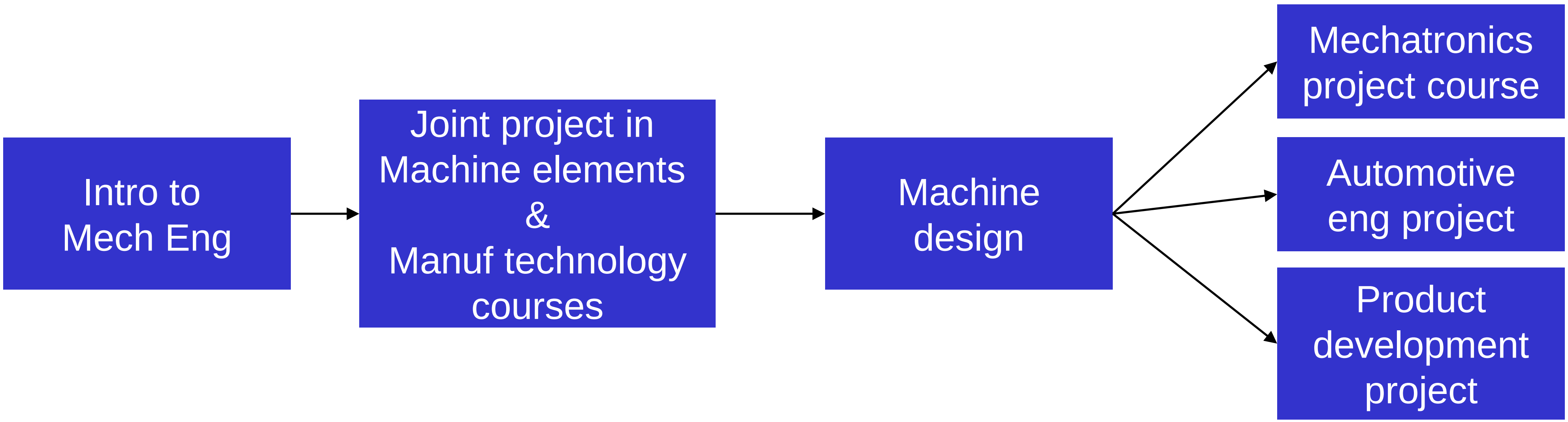
Solar-driven aircraft, KTH

Provide a platform for training other CDIO syllabus skills (teamwork, communications etc)

Formula Student, Chalmers

THERE SHOULD BE MULTIPLE DESIGN–BUILD PROJECTS IN THE CURRICULUM

Year 1 | **Year 2** | **Year 3** | **Year 4**



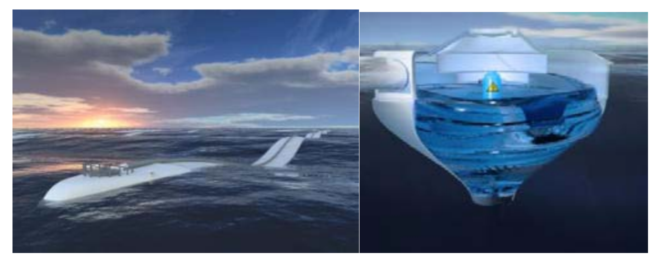
Year 1	Year 2	Year 3	Year 4
Creative, ”conceptual” design	Design for manufacturing	Redesign Multiple objectives	Creative design incl business aspects Cross-dept teams
Simple prototype Qualitative	More advanced prototype Some simulation Company is customer	Prototype as needed More simulation	Prototype Simulation as needed Company is customer

DESIGN-BUILD-TEST PROJECTS ADDRESS SUSTAINABLE INNOVATION

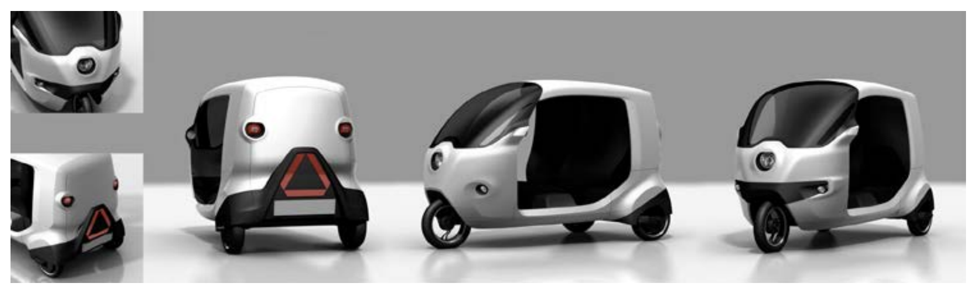
- **4th year Product development project course, interdisciplinary student teams**
- **Design-build and business development**
- **Collaboration with start ups and established firms**

Solar tracker actuator (SKF)

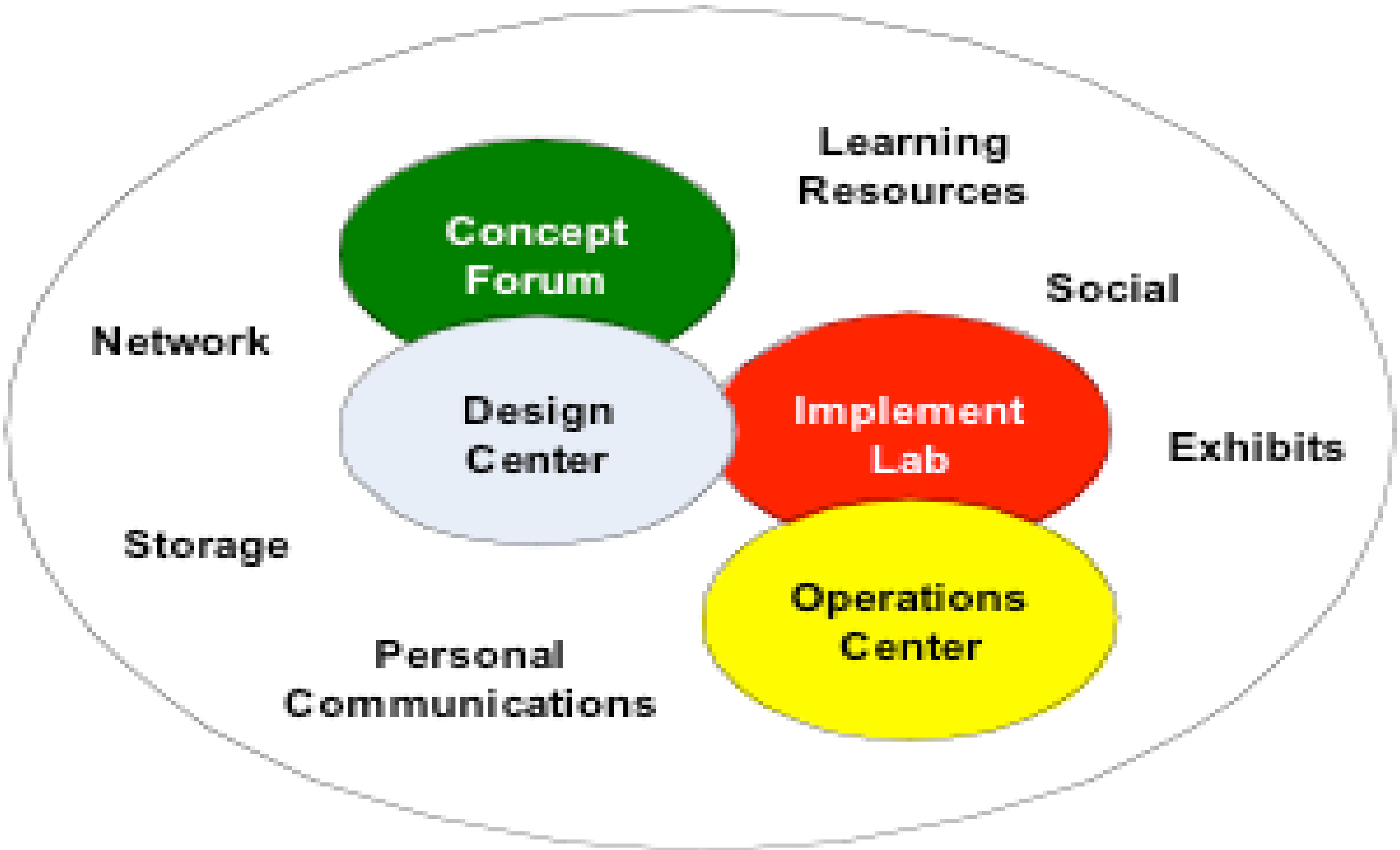
Wave energy (Vigor Wave)



Ultralight electric vehicle (CleanMotion)



STUDENT WORKSPACES FOR CDIO



EXAMPLE:
MIT AERO-ASTRO DEPARTMENT

Conceive

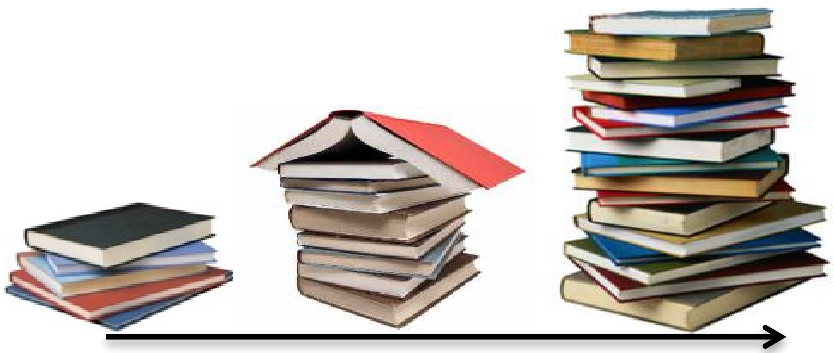
Design

Implement

Operate

CDIO AIMS FOR CO-EVOLUTION OF KNOWLEDGE AND SKILLS

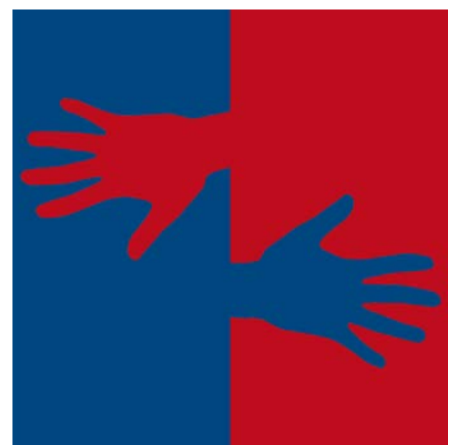
Integrated learning experiences develop **both** technical knowledge and “generic” skills (communication, teamwork, ethics, sustainability, etc)



Acquisition of technical knowledge

Development of generic skills

Knowledge & skills give each other meaning!



Source: Kristina Edström

DISCIPLINE-LED PROBLEM/ PRACTICE-BASED LEARNING

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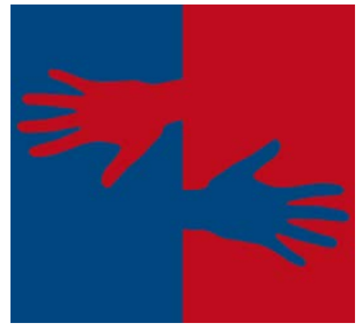


Discipline-led learning

- Well-structured knowledge base (”content”)
- What is known and what is not
- Evidence/theory, Model/reality
- Methods to further the knowledge frontier

CONNECTING WITH GENERIC 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

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.

It is about educating engineers who can actually communicate about engineering!

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

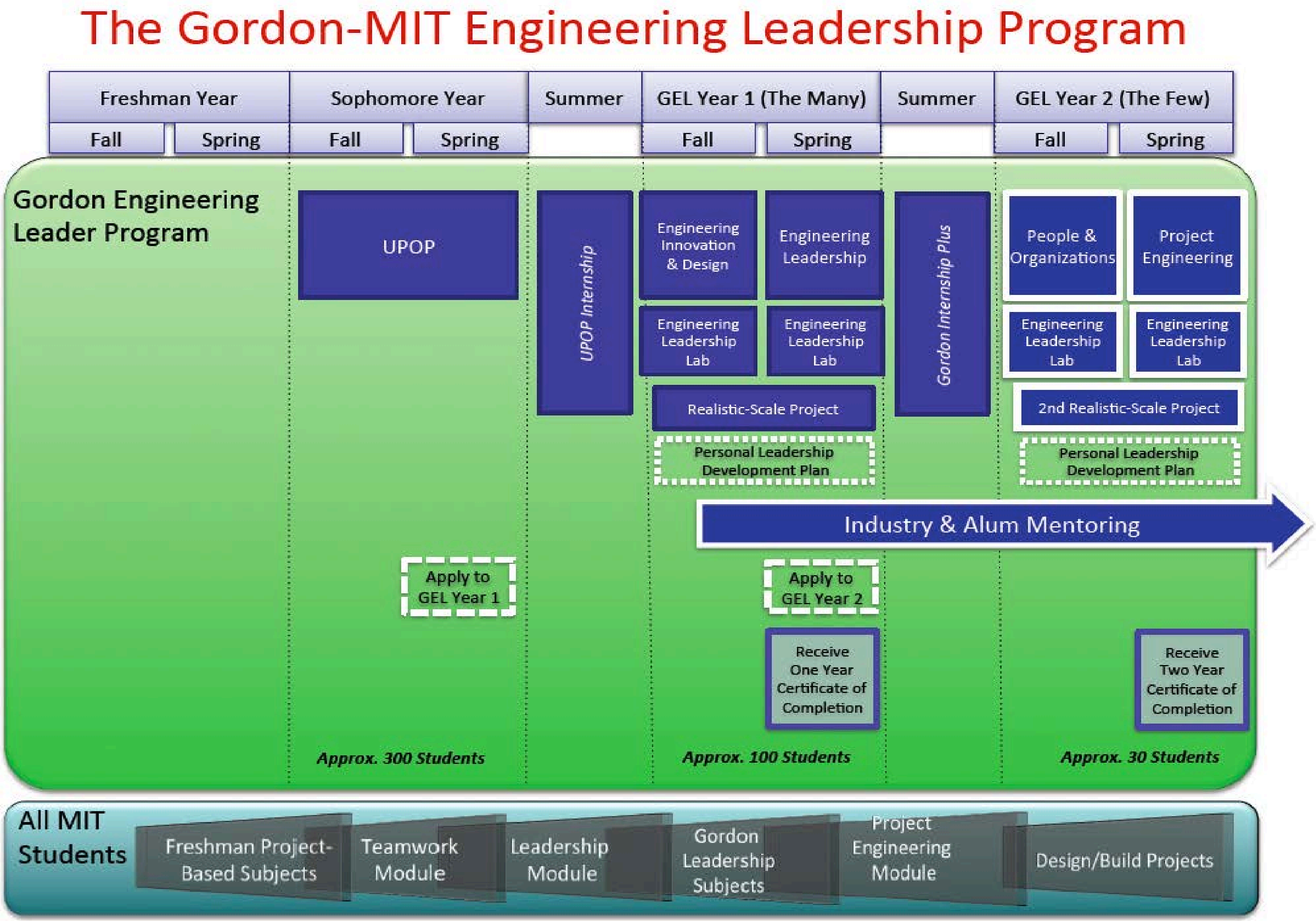
INTEGRATE THE CURRICULUM

An **integrated curriculum** has a systematic assignment of program outcomes to learning activities and features a explicit plan for progressive integration of generic skills

Planned learning sequence -- Vehicle Engineering -- KTH

CDIO Syllabus	Year 1		Year 2		Year 3	
3.2.3 Written communication	Introductory Course	Mech I	Mech II	Thermo-dynamics	Control Theory	FEM in Engineering
	Math I	Math II	Solid Mechanics	Math III	Electrical Eng.	Bachelor Thesis
3.3 Communi-cation in English	Physics	Numerical Methods	Product development	Fluid Mechanics	Statistics	
				Sound and Vibrations	Signal Analysis	Opti-mization

INTEGRATED LEADERSHIP TRAINING



DEVELOP ACTIVE AND EXPERIENTIAL LEARNING ACTIVITIES

Active and experiential learning engages students by setting teaching and learning in contexts that simulate engineering roles and practice

Reformed mathematics emphasizing simulation of realistic engineering problems

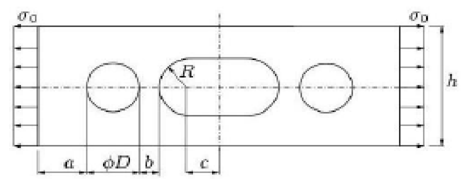
Working method based on modeling, simulation & analysis, MATLAB programming

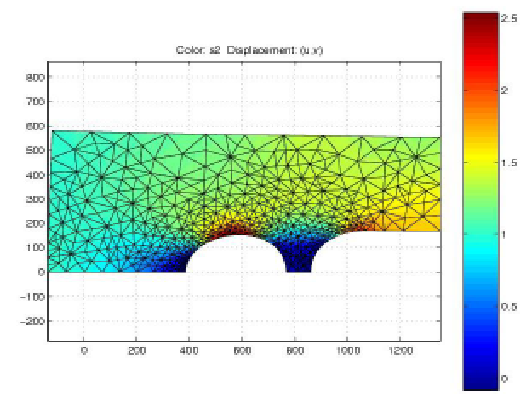
Motivated importance of mathematics and applied mechanics courses

Year 1 lab example

Analys av plan elastiska skiva med fyra hål

Beräkna spänningskoncentrationsfaktorn. Avgör om spänningshöjningarna vid hålen samverkar. Symmetrier skall utnyttjas.





THE 12 CDIO STANDARDS – GUIDELINES FOR EDUCATION DEVELOPMENT

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Program focus
1,2,3

- CDIO as Context
- CDIO Syllabus Outcomes
- Integrated Curriculum

CDIO
4,5,6

- Introduction to Engineering
- Design-Build Experiences
- CDIO Workspaces

Teaching & Learning
7,8

- Integrated Learning Experiences
- Active & Experiential Learning

Faculty development
9,10

- Enhancement of Faculty CDIO Skills
- Enhancement of Faculty Teaching Skills

Evaluation
11,12

- CDIO Skills Assessment
- CDIO Program Evaluation

CDIO IS A REFERENCE MODEL, NOT A PRESCRIPTION

Everything has to be *translated-transformed* to fit the context and conditions of each university / program

You are probably doing some CDIO elements already

Take what you want to use, transform it as you wish, give it a new name, assume ownership

CDIO provides a toolbox for working through the process

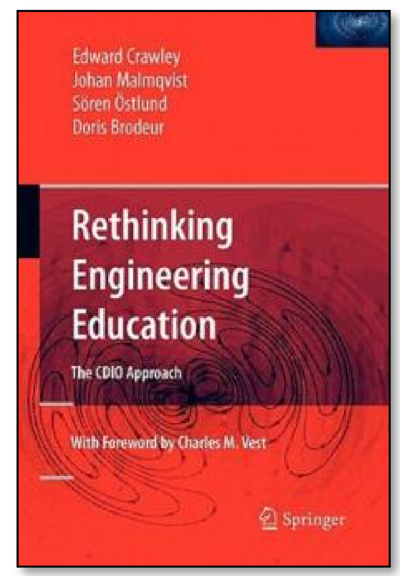
CONCLUDING REMARKS – WHAT IS CDIO

- An idea of what engineering students should learn: “Engineers who can engineer”

- A methodology for engineering education reform: The CDIO Syllabus and the 12 CDIO Standards

- A community: The CDIO Initiative with 107 universities as members

- To learn more, visit www.cdio.org or read *Rethinking Engineering Education: The CDIO Approach* by Crawley, Malmqvist, Östlund & Brodeur, 2007



Thank you for listening!

Any questions or comments?