Rethinking Engineering Education: The CDIO Approach

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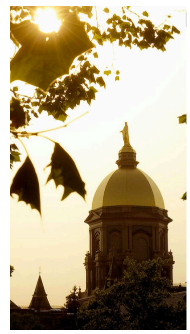
Electronic resources at: sites.google.com/site/rwscdio/



Your Questions

- As we begin the workshop, what **questions** do you hope the workshop will answer?
- What do you hope to learn about (knowledge), or learn how to do (skill), or form an opinion about (attitude)?
- Write your questions on Post-It notes. Use a separate note for each question.
- Share your questions with the person sitting next to you.

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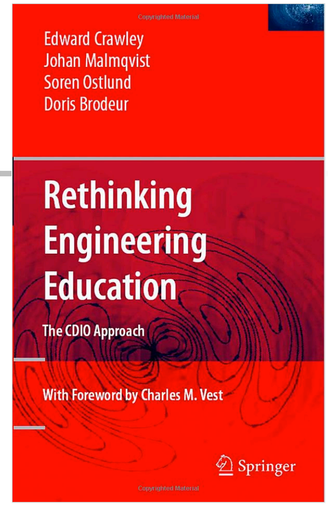
Outline of the morning



- What is CDIO?
- Why does CDIO exist?
- The Vision
- Why should you adopt CDIO?
- The CDIO Standards
  - What and How?
- Where Next?
- An Industrial Perspective
  - Dave Wisler
- Coffee
- Curriculum, Syllabus, and Accreditation Goals
  - Rob Niewoehner

What is CDIO?

- A voluntary, international organization that facilitates communication and cooperation among engineering schools to improve engineering curriculum.
- A set of **Standards** and tools for engineering program development and benchmarking, with a **Syllabus** to organize and describe outcomes
- A **brand** to label program approach

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Why CDIO?

- Why does the initiative exist?
- Recognition that undergraduate engineering education had shifted away from engineering practice
- 4 → 8 → ~97 engineering schools world wide working together to shift it back
- … and to meet professional practice elements required for accreditation

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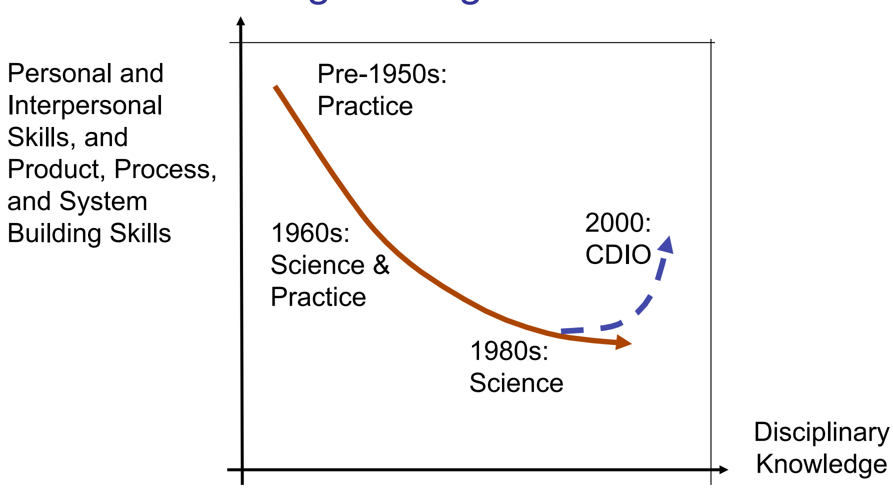
Notional Development of Engineering Education



Engineers need *both* dimensions, and we need to develop education that delivers both

USA – 11 ABET Student Outcomes

3 (a) an ability to apply knowledge of mathematics, science, and engineering
3 (b) an ability to design and conduct experiments, as well as to analyze and interpret data
3 (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
3 (d) an ability to function on multidisciplinary teams
3 (e) an ability to identify, formulate, and solve engineering problems
3 (f) an understanding of professional and ethical responsibility
3 (g) an ability to communicate effectively
3 (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
3 (i) a recognition of the need for, and an ability to engage in life-long learning
3 (j) a knowledge of contemporary issues
3 (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

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World Trend to Define Attributes / Competencies / Outcomes…

Canada – 12 CEAB Attributes

3.1.1 A knowledge base for engineering
3.1.2 Problem analysis
3.1.3 Investigation
3.1.4 Design
3.1.5 Use of engineering tools
3.1.6 Individual and team work
3.1.7 Communication skills
3.1.8 Professionalism
3.1.9 Impact (society, environment)
3.1.10 Ethics and equity
3.1.11 Economics, project management
3.1.12 Life-long learning

Washington Accord (1989)

Australia - Engineers Australia (1989)
Canada - Engineers Canada (1989)
Chinese Taipei - Inst. of Eng. Education (2007)
Hong Kong China - The Hong Kong Inst. of Eng. (1995)
Ireland - Engineers Ireland (1989)
Japan - Japan Accreditation Board for Eng. Educ. (2005)
Korea - Accreditation Board for Eng. Educ. (2007)
Malaysia - Board of Engineers Malaysia (2009)
New Zealand - Institution of Professional Eng. (1989)
Singapore - Institution of Engineers Singapore (2006)
South Africa - Engineering Council of South Africa (1999)
United Kingdom - Engineering Council UK (1989)
United States - Accreditation Board for Eng. and Tech. (1989)

Germany - German Accr. Agency for Study Prog. in Eng. …
India - Nat. Board of Accr. of All India Council for Tech. Educ.
Russia - Russian Association for Eng. Education
Sri Lanka - Institution of Engineers Sri Lanka

Six of the G8 are signatories
www.washingtonaccord.org

Why should you adopt CDIO?

- Value added for your students
  - and their future employers
- Value added for you as faculty
  - use the work of others within a
- Framework to meet accreditation(s)
  - Student outcome demonstration
  - Program of continuous improvement

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Vision

An education that stresses disciplinary knowledge set in the **context of professional practice**:

- A curriculum that is **centered on students**, multidisciplinary, and based on specified **learning outcomes**
- Featuring **active and experiential learning**, including a variety of project-based learning experiences
- Set in both classrooms and modern learning laboratories and **workspaces**
- Constantly improved through robust **assessment and evaluation** processes

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CDIO Standards V 2.0 (2010)

- Version 1 (2004) is largely unchanged with the update to V 2.0
- Details are clearer in the fine print

http://www.cdio.org/knowledge-library/documents/cdio-standards-v-20-customized-rubrics

- In the resource package
- You probably already meet or aspire to most of these standards!

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Standard 1 – The Context

Adoption of the principle that product, process, and system lifecycle development and deployment -- Conceiving, Designing, Implementing and Operating -- are the context for engineering education

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Standard 1 – The Context

Adoption of the principle that product, process, and system lifecycle development and deployment -- Conceiving, Designing, Implementing and Operating -- are the context for engineering education

Description: A CDIO program is based on the principle that product, process, and system lifecycle development and deployment are the appropriate context for engineering education. *Conceiving--Designing--Implementing--Operating* is a model of the entire product, process, and system lifecycle. The *Conceive* stage includes defining customer needs; considering technology, enterprise strategy, and regulations; and, developing conceptual, technical, and business plans. The *Design* stage focuses on creating the design, that is, the plans, drawings, and algorithms that describe what will be implemented. The *Implement* stage refers to the transformation of the design into the product, process, or system, including manufacturing, coding, testing and validation. The final stage, *Operate*, uses the implemented product or process to deliver the intended value, including maintaining, evolving and retiring the system.

The product, process, and system lifecycle is considered the context for engineering education in that it is part of the cultural framework, or environment, in which technical knowledge and other skills are taught, practiced and learned. The principle is adopted by a program when there is explicit agreement of faculty to transition to a CDIO program, and support from program leaders to sustain reform initiatives.

Rationale: Beginning engineers should be able to Conceive--Design--Implement--Operate complex value-added engineering products, processes, and systems in modern team-based environments. They should be able to participate in engineering processes, contribute to the development of engineering products, and do so while working to professional standards in any organization. This is the essence of the engineering profession.

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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**
  - **Base them on the comprehensive CDIO Syllabus for consistency and completeness**

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Standard 3 – Integrated Curriculum

- A curriculum designed with mutually supporting disciplinary courses, with an explicit plan to integrate personal and interpersonal skills, and product, process, and system building skills

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Standard 4 – Introduction to Engineering

- An introductory course that provides the framework for engineering practice in product, process, and system building, and introduces essential personal and interpersonal skills

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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

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Standard 6 – Engineering Workspaces

- Engineering workspaces and laboratories that support and encourage hands-on learning of product, process, and system building, disciplinary knowledge, and social learning

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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

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Standard 8 – Active Learning

- Teaching and learning based on active experiential learning methods

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Standard 9 – Enhancement of Faculty Competence

- Actions that enhance faculty competence in personal and interpersonal skills, and product, process, and system building skills

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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

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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

Standard 12 – Program Evaluation

- A system that evaluates programs against these twelve standards, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement

The CDIO Standards

1. The Context
2. Learning Outcomes
3. Integrated Curriculum
4. Introduction to Engineering
5. Design-Implement Experiences
6. Engineering Workspaces
7. Integrated Learning Experiences
8. Active Learning
9. Enhancement of Faculty Skills Competence
10. Enhancement of Faculty Teaching Competence
11. Learning Assessment
12. Program Evaluation

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The Learning Context: Professional Practice

- A focus on the needs of customers, clients, and patients
- Delivery of products, processes, and services
- Incorporation of inventions and new technologies
- Stewardship of the environment
- A focus on solutions, not disciplines
- Working with others and providing leadership
- Communicating effectively
- Working efficiently, within resources, and/or profitably

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A Learning Context for Engineering: CDIO

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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

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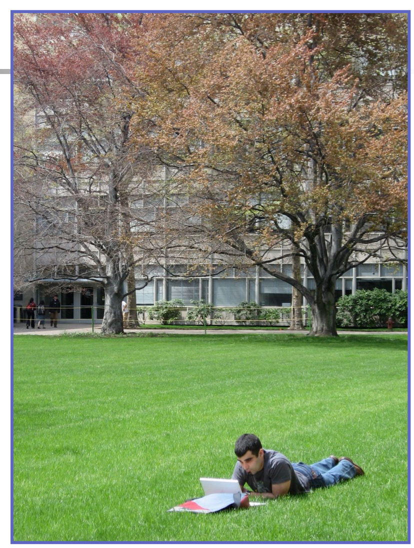
Central Questions

- **What** knowledge, skills and attitudes should students possess as they graduate from university?
- **How** can we do better at ensuring that students learn these skills?



Early Fall at MIT (2002)

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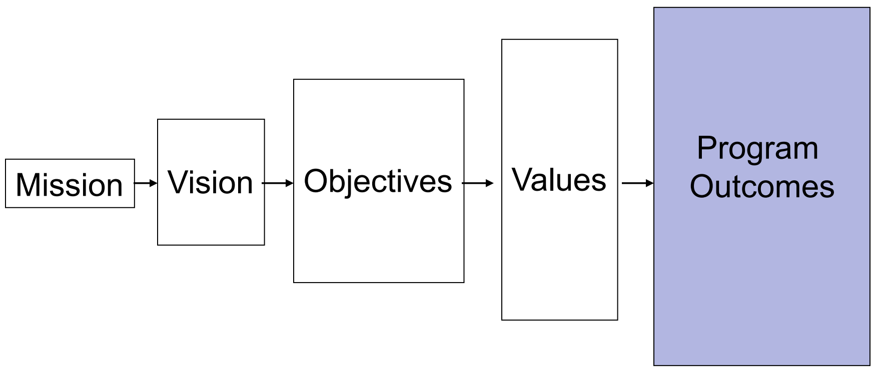
Program Outcomes Derived From Mission, Vision, Objectives, and Values



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The *CDIO Syllabus v 2.0* as Program Outcomes

1.0 Disciplinary Knowledge and Reasoning	1.1	Demonstrate a capacity to use the principles of the underlying sciences
	1.2	Apply the principles of fundamental engineering science
	1.3	Demonstrate a capacity to apply advanced engineering knowledge in the professional areas of engineering
2.0 Personal and Professional Skills and Attributes	2.1	Analyze and solve engineering problems
	2.2	Conduct investigations and experiments about engineering problems
	2.3	Think systemically
	2.4	Demonstrate personal and professional habits that contribute to successful engineering practice
	2.5	Demonstrate ethics, equity, and other responsibilities in engineering practice

The *CDIO Syllabus v 2.0* as Program Outcomes (cont.)

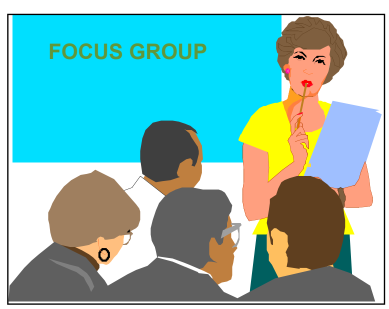
3.0 Interpersonal Skills	3.1 3.2 3.3	Lead and work in groups Communicate effectively Communicate effectively in one or more foreign languages.
4.0 CDIO	4.1 4.2 4.3 4.4 4.5 4.6 4.7 4.8	Recognize the importance of the social context in the practice of engineering Appreciate different enterprise cultures and work successfully in organizations Conceive and develop engineering systems Design complex engineering systems Implement processes of hardware and software and manage the implementation process Operate complex systems and processes and manage operations Lead engineering endeavors Demonstrate the skills of entrepreneurship

Validation With Key Stakeholders

Stakeholders are individuals or groups who share an interest, and have an investment, in graduates of a particular program. They benefit from the program's success, and hold programs accountable for results.

Methods to get stakeholder input

- Interviews
- Focus-group discussions
- Surveys
- Peer review
- Workshops



Self Evaluation on 2.4 - 4.8

- Rate yourself on each of the outcomes and write your score on the sheet

1. To have experienced or been exposed to
2. To be able to participate in and contribute to
3. To be able to understand and explain
4. To be skilled in the practice and implementation of
5. To be able to lead or innovate in

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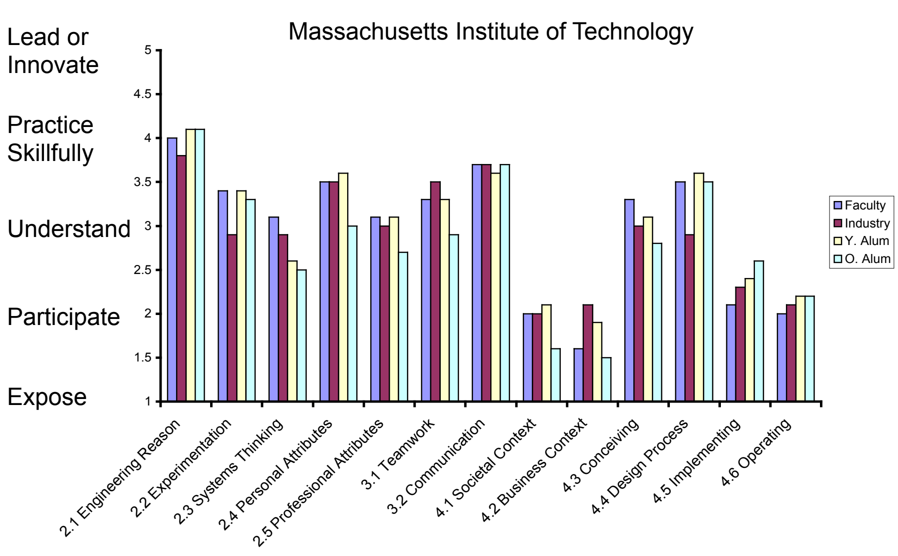
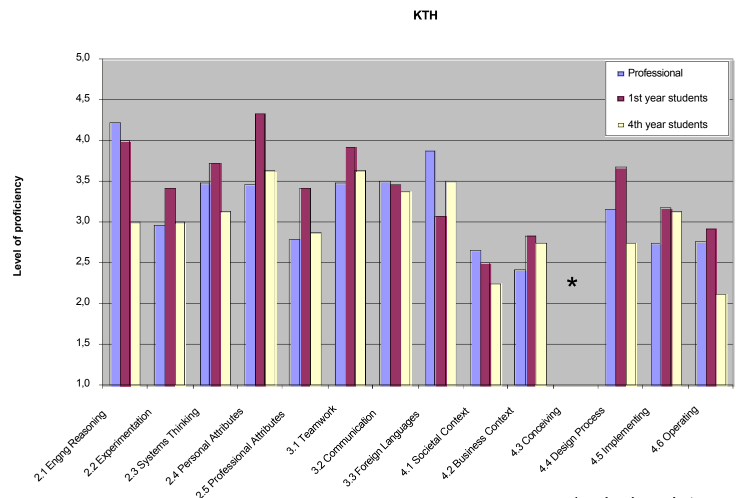
Validation of CDIO Learning Outcomes



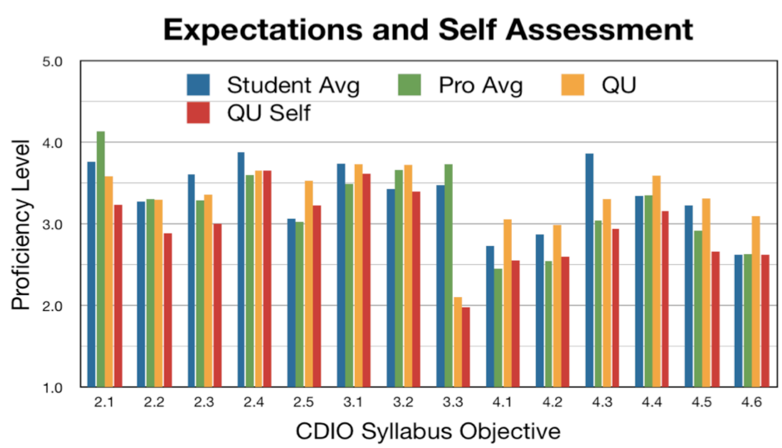
Validation of CDIO Learning Outcomes

Kungliga Tekniska Högskolan (KTH), Stockholm



* missing data

Queen's 4th Year Students



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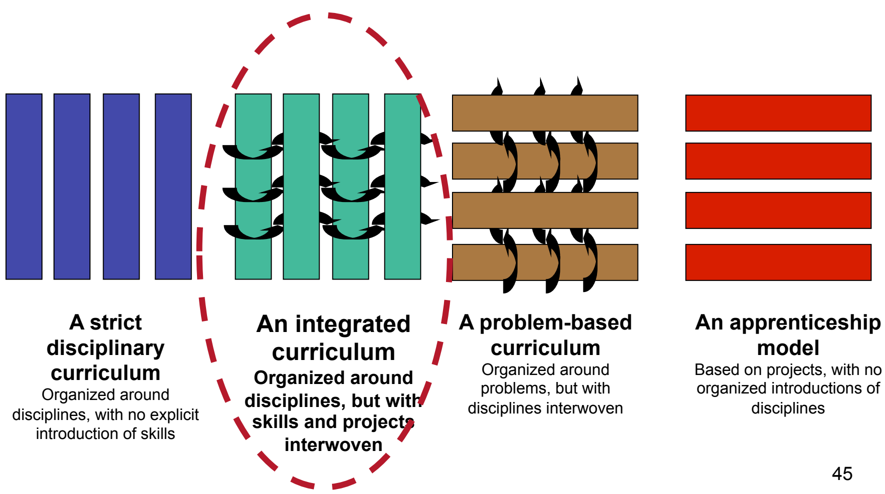
CDIO Syllabus	ABET EC2010 Criterion 3										
	a	b	c	d	e	f	g	h	i	j	k
1.1 Knowledge of Underlying Mathematics, Science	■										
1.2 Core Engineering Fundamental Knowledge	■										
1.3 Adv. Engr. Fund. Knowledge, Methods, Tools	□										■
2.1 Analytical Reasoning and Problem Solving					■						□
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				

Figure 4. The CDIO Syllabus correlated with ABET EC2010 Criterion 3

Sample Curriculum Structures

(Disciplines run vertically; projects and skills run horizontally.)



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Sample Integrated Curriculum Design

Universidad Tecnológica Centroamericana (UNITEC), Honduras

	Habilidades y Atributos Personales																																
	2.1			2.2			2.3			2.4			2.5			2.6			2.7			2.8			2.9			2.10			2.11		
Asignatura	I	E	A	I	E	A	I	E	A	I	E	A	I	E	A	I	E	A	I	E	A	I	E	A	I	E	A	I	E	A	I	E	A
Algebra	x	x	x																x	x		x											
Administracion 1							x																		x								
Español				x																													
Ofimatica 1																															x		
Geomet. Trigonom.																																	
Intro. Ing. Industrial																																	
Historia de Honduras							x																		x								
Ofimatica 2	x																																
Calculo 1 Diferencial																							x										
Quimica General																																	
Sociologia							x						x	x		x	x																
Ofimatica 3																															x	x	
Calculo 1 Integral	x																				x												
Analisis Contable 1	x																																
Elect. Arte/Deporte										x																							
Idioma 1																															x	x	x
Calculo 2 Geom. Analit.	x	x	x																		x		x	x									
Algebra Lineal																																	
Mercadotecnia 1	x									x															x	x							
Idioma 2																																	x
Ecuac. Diferenciales																							x										
Analisis Contable 2					x																												
Fisica 1																			x	x	x												
Idioma 3	x	x																															
Estad. Matematica 1			x		x																												
Dibujo Tecnico																												x	x				
Fisica 2																																	
Idioma 4																																	

CDIO Standard 4: Introduction to Engineering

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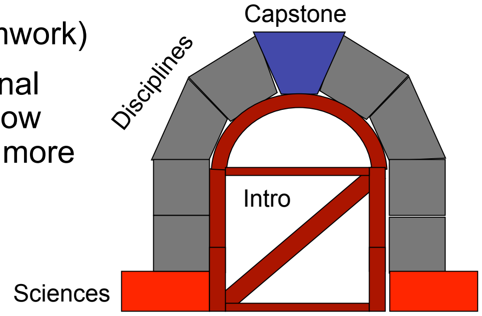
An introductory course that provides the framework for engineering practice in product, process, and system building, and introduces essential personal and interpersonal skills.

- Stimulates students' interest in engineering
- Strengthens student motivation
- Provides an early start to the development of the essential skills described in the *CDIO Syllabus*.

(See The CDIO Standards v 2.0)

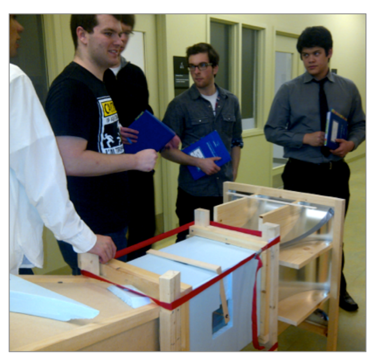
Introductory Engineering Course

- To motivate students to study engineering
- To provide early exposure to system building
- To teach some early and essential skills (*e.g.*, teamwork)
- To provide a set of personal experiences which will allow early fundamentals to be more deeply understood



Introductory Course Contents

- Lectures on information retrieval, project management, group dynamics,…
- Guest seminars from industry
- Teamwork (2-6) on design-implement projects, case-studies,…
- Communication (oral and written)
- Verification of students' project performance



École Polytechnique Montréal

Changes in the Learning Culture

- Learning as individuals → Learning with others
- Competition between students → Collaboration
- Passive listener → Challenged learner
- Get the right answer → Learn from mistakes
- Compartmentalised curriculum → Integrated curriculum content
- Artificial practical exercises → Real life situations
- Theory = chore to learn → Theory = necessary tool
- Students are non confident → Students take responsibilities
- Mind-set oriented in the present → Mind-set future oriented
- Problem seeking → Problem solving

McCartan et al. (2007), Queen's University Belfast, University of Liverpool

Discussion: Introductory Course

Skyscraper Workshop
École Polytechnique Montréal

1. What introductory experience is proposed / exists in your own institution ?
2. What is the level of participation of practicing engineers from industry ?
3. How will you or do you evaluate the success of the the students / the course?

CDIO Standard 5 :
Design-Implement Experiences

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A curriculum that includes two or more design-implement experiences, including one at a basic level and one at an advanced level.

- Add realism to the curriculum
- Illustrate connections between engineering disciplines
- Foster students' creative abilities
- Are motivating for students

(See The CDIO Standards v 2.0)

Design-Implement Experiences

- Student-centered and self-directed
- Organized around real-world problems
- Focused on authentic skills
- Collaborative
- With faculty as facilitators
- Two or more projects at basic and advanced levels
- Professional practice right from the start

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Design-Implement Experiences

Design-implement experiences are instructional events in which learning occurs through the creation of a product, process, or system

- They should be advanced to a state where:
  - they can demonstrate that they meet the requirements
  - potential improvements can be identified
- The level of complexity can vary from basic to advanced
- They may focus on **Conceive**, **Design**, **Implement**, or **Operate**, or any combination of these stages

Rationale for Design-Implement Experiences

~~**A fra[illegible]k for studer[illegible]o build [illegible]**~~

A framework for students to learn engineering by building things

The Design-Implement Experience may change from year-to-year, but the **learning objectives** remain the same

Sample Learning Objectives

Learning Objectives

Work effectively in a team

Communication

Analyze technical problems

Solve technical problems

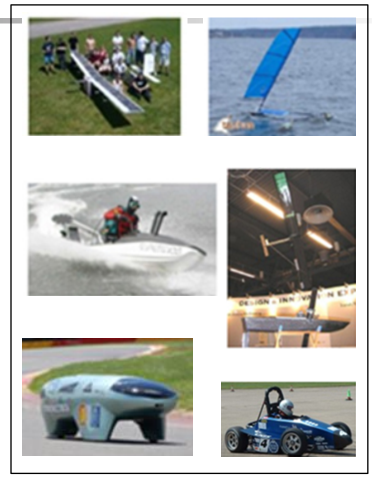
Use appropriate engr. methods

Learn how to make estimates

Develop concepts

Use acquired knowledge

Assess the quality of work



Kungliga Tekniska Högskolan (KTH)

Levels Of Project Complexity

	Increasing Complexity ➔➔➔		
Activity	I-O	D-I-O	C-D-I-O
Structure	Structured		Unstructured
Solution	Known		Unknown
Team	Individual	Small Team	Large Team
Duration	Days	Weeks	Months

CDIO Standard 6 :
Engineering Workspaces

Workspaces and laboratories that support and encourage hands-on learning of product, process, and system building, disciplinary knowledge, and social learning.

- Students are directly engaged in their own learning
- Settings where students learn from each other
- Newly created or remodeled from existing spaces

(See The CDIO Standards v 2.0)

Student-Centered Workspaces

Knowledge Reinforcement **Knowledge Discovery**

System Building **Community Building**

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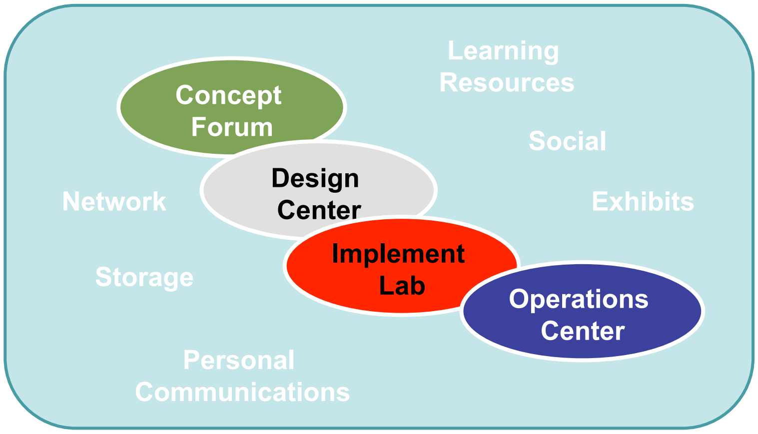
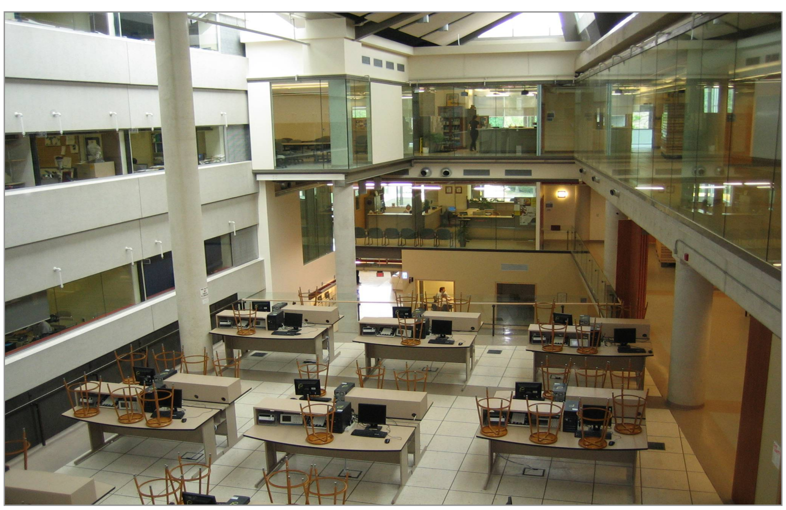
Designing the cdio Learning Environment

CDIO Workspace



Engineering Integrated Learning Centre



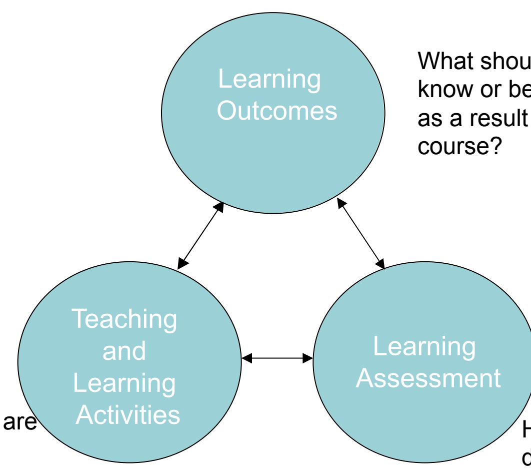
Queen's University, Canada

Modular Design / Build Space

Singapore Polytechnic

cdio™

Constructive Alignment

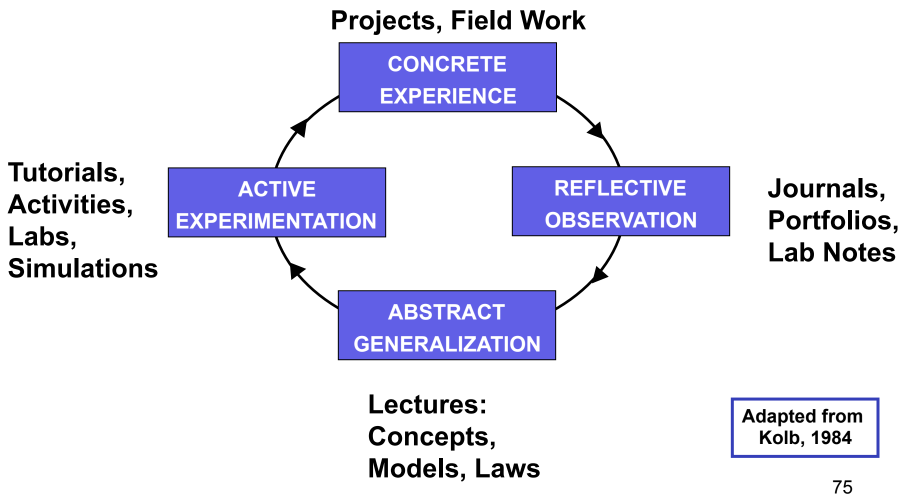


What should students know or be able to do as a result of the course?

What activities are appropriate for students in order to achieve the intended learning outcomes?

How can students demonstrate that they have achieved the desired outcomes?

Student-Centered Teaching and Learning



Adapted from Kolb, 1984

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Students at the Center

	STUDENT	TEACHER	EXAMPLES
Stage 1	Dependent	Authority, Coach	Coaching with immediate feedback. Drill. Informational lecture. Overcoming deficiencies and resistance.
Stage 2	Interested	Motivator, Guide	Inspiring lecture plus guided discussion. Goal-setting and learning strategies.
Stage 3	Involved	Facilitator	Discussion facilitated by teacher who participates as equal. Seminar. Group projects.
Stage 4	Self-directed	Consultant, Delegator	Internship, dissertation, individual work or self-directed study group.

Adapted from Grow, 1991

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Changing Roles for Instructors

	T1 Authority, Expert	T2 Salesperson, Motivator	T3 Facilitator	T4 Delegator
S4 Self-Directed Learner	Severe Mismatch	Mismatch	Near Match	Match
S3 Involved Learner	Mismatch	Near Match	Match	Near Match
S2 Interested Learner	Near Match	Match	Near Match	Mismatch
S1 Dependent Learner	Match	Near Match	Mismatch	Severe Mismatch

Adapted from Grow, 1991

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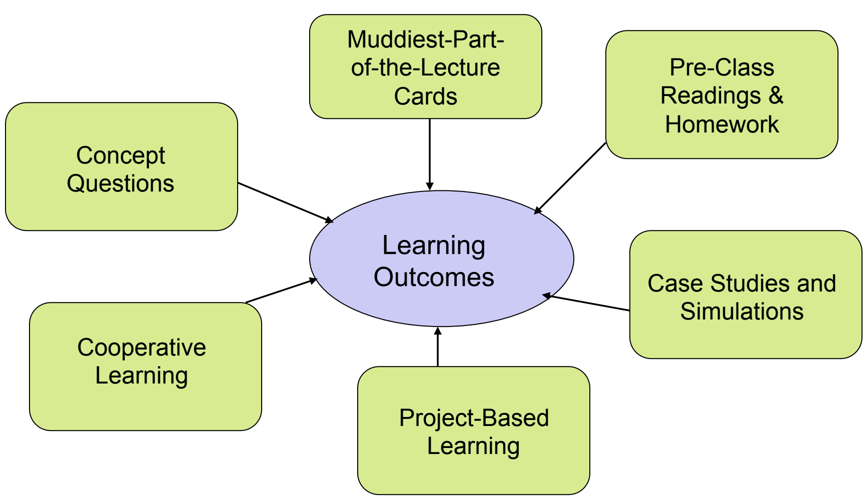
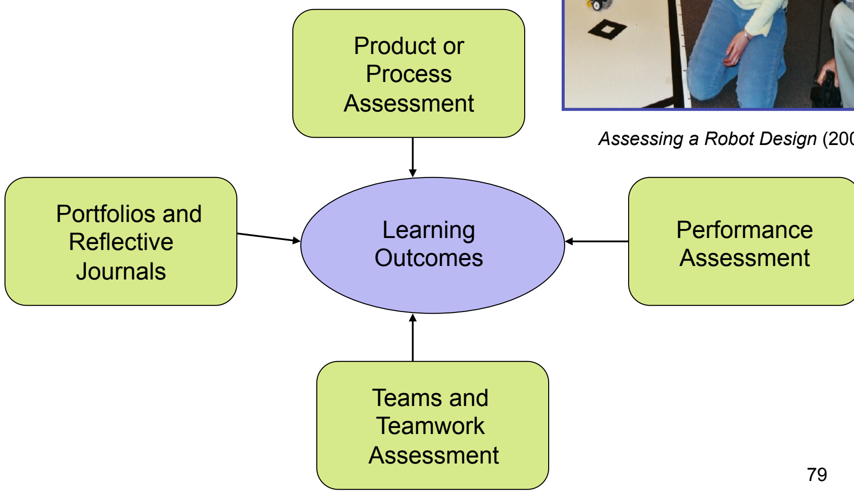
Methods That Engage Learners



Student Learning Assessment

Assessing a Robot Design (2002)



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One of the hardest parts, needs a whole workshop and more

Faculty Development

Concurrent with curriculum change, there should be programs of faculty development.

- Enhancement of the personal, interpersonal, system, and professional skills that are expected from graduates
- Improvement of student-centered learning and assessment methods

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After Dave and Coffee

The CDIO Standards

1. The Context
2. **Learning Outcomes**
3. **Integrated Curriculum**
4. Introduction to Engineering
5. Design-Implement Experiences
6. Engineering Workspaces
7. **Integrated Learning Experiences**
8. Active Learning
9. Enhancement of Faculty Skills Competence
10. Enhancement of Faculty Teaching Competence
11. Learning Assessment
12. Program Evaluation

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This Afternoon:

The CDIO Standards

1. The Context
2. Learning Outcomes
3. Integrated Curriculum
4. Introduction to Engineering
5. Design-Implement Experiences
6. Engineering Workspaces
7. Integrated Learning Experiences
8. Active Learning
9. Enhancement of Faculty Skills Competence
10. Enhancement of Faculty Teaching Competence
11. **Learning Assessment**
12. **Program Evaluation**

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Support Of Early Adopters

With any change process, some individuals are inclined to try new approaches in the early stages.

- Identification and engagement of early adopters
- Opportunities, resources, and celebrations of the their successes
- Next wave of individuals who follow the example of early adopters
- Identification of the most respected members of the learning community

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Rating The Challenges

What are your main challenges to designing and implementing a curriculum that is centered on students and focused on outcomes?

CHALLENGE	A A BIG CHALLENGE	B A MODERATE CHALLENGE	C NOT SO DIFFICULT
Identifying and addressing the needs of program stakeholders			
Persuading faculty to shift their focus to an outcomes-based approach			
Integrating professional practice throughout the curriculum			
Providing relevant experiences for students in a cost-effective way			
Sustaining enthusiasm for curriculum reform beyond the initial stages			

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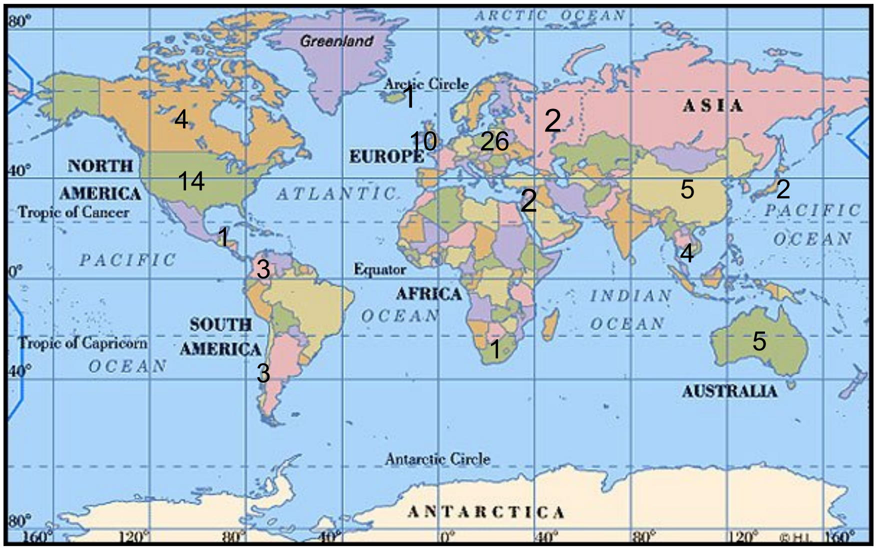
CDIO Collaborators -- as of 17 May 2012



(N = 83, but now up to 97 in November 2012)

For more information about cdio™

- Visit the CDIO website, http://www.cdio.org
- Read *Rethinking Engineering Education: The CDIO Approach* (E. F. Crawley, Johan Malmqvist, Sören Östlund, Doris R. Brodeur, New York: Springer, 2007)
- Participate in another Introductory CDIO Workshop at a regional or international meeting
- Attend the annual international conference
- Contact other CDIO universities

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