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.
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
Why CDIO?

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

Notional Development of Engineering Education

Pre-1950s: Practice
1960s: Science & Practice
1980s: Science
2000: CDIO

Personal and Interpersonal Skills, and Product, Process, and System Building Skills
Disciplinary Knowledge

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.

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


- Australia - Engineers Australia (1989)
- Canada - Engineers Canada (1989)
- Hong Kong China - The Hong Kong Inst. of Eng. (1995)
- Ireland - Engineers Ireland (1989)
- Malaysia - Board of Engineers Malaysia (2009)
- South Africa - Engineering Council of South Africa (1999)
- 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

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
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
- 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
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.

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
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

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
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

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
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

Standard 8 – Active Learning

- Teaching and learning based on active experiential learning methods
Standard 9 – Enhancement of Faculty Competence

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

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
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

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
A Learning Context for Engineering: CDIO

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

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

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.)

<table>
<thead>
<tr>
<th>3.0 Interpersonal Skills</th>
<th>3.1 Lead and work in groups</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>3.2 Communicate effectively</td>
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<td>3.3 Communicate effectively in one or more foreign languages.</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>4.0 CDIO</th>
</tr>
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<tbody>
<tr>
<td>4.1 Recognize the importance of the social context in the practice of engineering</td>
</tr>
<tr>
<td>4.2 Appreciate different enterprise cultures and work successfully in organizations</td>
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<td>4.3 <strong>Conceive and develop engineering systems</strong></td>
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<td>4.4 Design complex engineering systems</td>
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<td>4.5 Implement processes of hardware and software and manage the implementation process</td>
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<td>4.6 Operate complex systems and processes and manage operations</td>
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<td>4.7 Lead engineering endeavors</td>
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<td>4.8 Demonstrate the skills of entrepreneurship</td>
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</tbody>
</table>

### 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

Validation of CDIO Learning Outcomes

Massachusetts Institute of Technology

Expose
Participate
Understand
Practice Skillfully
Lead or Innovate
Validation of CDIO Learning Outcomes

Kungliga Tekniska Högskolan (KTH), Stockholm

KTH

Level of proficiency

Professional 1st year students 4th year students

* missing data

Queen’s 4th Year Students

Expectations and Self Assessment

Proficiency Level

CDIO Syllabus Objective

Student Avg Pro Avg QU QU Self

1.0 2.0 3.0 4.0 5.0

2.1 2.2 2.3 2.4 2.5 3.1 3.2 4.1 4.2 4.3 4.4 4.5 4.6
Sample Curriculum Structures

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

<table>
<thead>
<tr>
<th>CDIO Syllabus</th>
<th>ABET EC2010 Criterion 3</th>
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<tbody>
<tr>
<td>1.1 Knowledge of Underlying Mathematics, Science</td>
<td>a b c d e f g h i j k</td>
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<td>1.2 Core Engineering Fundamental Knowledge</td>
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<td>1.3 Adv. Engr. Fund. Knowledge, Methods, Tools</td>
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<td>2.1 Analytical Reasoning and Problem Solving</td>
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<td>2.3 System Thinking</td>
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<td>2.4 Attitudes, Thought and Learning</td>
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<td>2.5 Ethics, Equity and Other Responsibilities</td>
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<td>4.1 External, Societal and Environmental Context</td>
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<td>4.2 Enterprise and Business Context</td>
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<td>4.3 Conceiving, Systems Engr. and Management</td>
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<td>4.4 Designing</td>
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<td>4.5 Implementing</td>
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<td>4.6 Operating</td>
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Figure 4. The CDIO Syllabus correlated with ABET EC2010 Criterion 3

A strict disciplinary curriculum
Organized around disciplines, with no explicit introduction of skills

An integrated curriculum
Organized around disciplines, but with skills and projects interwoven

A problem-based curriculum
Organized around problems, but with disciplines interwoven

An apprenticeship model
Based on projects, with no organized introductions of disciplines
Sample Integrated Curriculum Design

Universidad Tecnológica Centroamericana (UNITEC), Honduras

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CDIO 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.

- 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

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 students / the course?

Skyscraper Workshop
École Polytechnique Montréal
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.

- 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
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

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

<table>
<thead>
<tr>
<th>Increasing Complexity</th>
<th>Activity</th>
<th>Structure</th>
<th>Solution</th>
<th>Team</th>
<th>Duration</th>
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<tbody>
<tr>
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<td>I-O</td>
<td>Structured</td>
<td>Known</td>
<td>Individual</td>
<td>Days</td>
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<td>D-I-O</td>
<td></td>
<td>Unknown</td>
<td>Small Team</td>
<td>Weeks</td>
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<td>C-D-I-O</td>
<td>Unstructured</td>
<td></td>
<td>Large Team</td>
<td>Months</td>
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</tbody>
</table>
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)
Designing the Learning Environment

CDIO Workspace

Concept Forum
Learning Resources
Social
Exhibits
Network
Storage
Personal Communications
Design Center
Implement Lab
Operations Center

Engineering Integrated Learning Centre

Queen’s University, Canada
Modular Design / Build Space

Constructive Alignment

Learning Outcomes

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

Teaching and Learning Activities

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

Learning Assessment

How can students demonstrate that they have achieved the desired outcomes?
### Student-Centered Teaching and Learning

**Projects, Field Work**

- **Concrete Experience**
- **Active Experimentation**
- **Reflective Observation**
- **Abstract Generalization**

**Tutorials, Activities, Labs, Simulations**

**Lectures:**
- Concepts, Models, Laws

**Journals, Portfolios, Lab Notes**

Adapted from Kolb, 1984

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### Students at the Center

<table>
<thead>
<tr>
<th>Stage</th>
<th>Student</th>
<th>Teacher</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dependent</td>
<td>Authority, Coach</td>
<td>Coaching with immediate feedback. Drill. Informational lecture. Overcoming deficiencies and resistance.</td>
</tr>
<tr>
<td>2</td>
<td>Interested</td>
<td>Motivator, Guide</td>
<td>Inspiring lecture plus guided discussion. Goal-setting and learning strategies.</td>
</tr>
<tr>
<td>3</td>
<td>Involved</td>
<td>Facilitator</td>
<td>Discussion facilitated by teacher who participates as equal. Seminar, Group projects.</td>
</tr>
<tr>
<td>4</td>
<td>Self-directed</td>
<td>Consultant, Delegator</td>
<td>Internship, dissertation, individual work or self-directed study group.</td>
</tr>
</tbody>
</table>

Adapted from Grow, 1991
### Changing Roles for Instructors

<table>
<thead>
<tr>
<th>S1 Dependent Learner</th>
<th>T1 Authority, Expert</th>
<th>T2 Salesperson, Motivator</th>
<th>T3 Facilitator</th>
<th>T4 Delegator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Match</td>
<td>Near Match</td>
<td>Mismatch</td>
<td>Match</td>
<td>Severe Mismatch</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>S2 Interested Learner</th>
<th>Mismatch</th>
<th>Near Match</th>
<th>Match</th>
<th>Near Match</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>S3 Involved Learner</th>
<th>Match</th>
<th>Near Match</th>
<th>Match</th>
<th>Near Match</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>S4 Self-Directed Learner</th>
<th>Severe Mismatch</th>
<th>Mismatch</th>
<th>Near Match</th>
<th>Match</th>
</tr>
</thead>
</table>

Adapted from Grow, 1991

### Methods That Engage Learners

- Learning Outcomes
  - Muddiest-Part-of-the-Lecture Cards
  - Pre-Class Readings & Homework
  - Case Studies and Simulations
  - Project-Based Learning

- Concept Questions
- Cooperative Learning
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

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

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
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9. Enhancement of Faculty Skills Competence
10. Enhancement of Faculty Teaching Competence
11. Learning Assessment
12. Program Evaluation
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 their successes
- Next wave of individuals who follow the example of early adopters
- Identification of the most respected members of the learning community

Rating The Challenges

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

<table>
<thead>
<tr>
<th>CHALLENGE</th>
<th>A BIG CHALLENGE</th>
<th>B MODERATE CHALLENGE</th>
<th>C NOT SO DIFFICULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identifying and addressing the needs of program stakeholders</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Persuading faculty to shift their focus to an outcomes-based approach</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integrating professional practice throughout the curriculum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Providing relevant experiences for students in a cost-effective way</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sustaining enthusiasm for curriculum reform beyond the initial stages</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CDIO Collaborators -- as of 17 May 2012

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

For more information about

- 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