cdio

CONCEIVE DESIGN IMPLEMENT OPERATE™

Reforming engineering education

The CDIO Initiative

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Reforming Engineering Education

The CDIO Initiative

CDIO stands for *Conceive – Design – Implement – Operate*. It's an innovative educational framework for producing the next generation of engineering leaders. Industry benefits because CDIO produces engineers who have the knowledge, talents and experience it specifically needs. Educators are interested because the CDIO syllabus forms a basis for curricular planning and outcome based assessment that is universally adaptable for all engineering schools. And, students are enthusiastic because they're graduating with a unique array of personal, interpersonal, and system-building experiences that allows them to excel in real engineering teams, and produce new products and systems.

The vision

Academia's task is to produce technically expert, socially aware, and entrepreneurally astute engineers. This is essential to sustaining productivity, innovation, and excellence in an environment that is increasingly based on technologically complex systems. In recent years, conflicts have arisen between engineering education pedagogy and real-world demands on graduating engineers. In order to resolve these conflicts of contemporary engineering education, we must conceptualize and develop a new vision.

The CDIO Initiative envisions an education that stresses the fundamentals, set in the context of Conceiving – Designing – Implementing – Operating systems and products. However, in addition to stressing technical fundamentals, it must prepare them to play successful roles in developing system products. Its curriculum is organized around the disciplines, but with CDIO activities highly interwoven.

Disciplines are mutually supporting and interacting. The program must be rich with student projects complemented by internships in industry, and feature active, experiential, and group learning set in both the classroom and a modern learning workspace/laboratory, networked with the outside world. It is constantly improved through a comprehensive assessment and evaluation process.

The need for CDIO

Throughout much of the 20th century engineering education offered an effective exposure to hands-on practice. It was taught by practicing engineers, and it focused on solving tangible problems as students learned to conceptualize and design products and systems. But, as scientific and technical knowledge expanded rapidly during the latter 1900s, engineering education evolved into the teaching of engineering science, de-emphasizing actual engineering practice.

Industry leaders began to find that graduating students, while technically adept, lacked many abilities required in real-world engineering situations. To delineate their needs, some major companies created lists of abilities they want their engineers to possess. To encourage schools to meet real world needs and rethink their educational designs, the Accreditation Board for Engineering and Technology listed its expectations for graduating engineers. These lists identified the destination; it was up to educators to plan the route.

Aware of the growing tension between scientific and practical engineering demands, an international group of university engineering academics took up the challenge to reform engineering education. The result of that endeavor is the CDIO Initiative.

American engineering students hone their hands-on skills during the 1940s.

Determining abilities, goals, proficiencies

The first task we shouldered turning our vision into a model program was developing and codifying a comprehensive understanding of abilities needed by contemporary engineers. This task was accomplished through the use of stakeholder focus groups comprising engineering faculty, students, industry representatives, university review committees, alumni, and senior academicians. The focus groups were asked, "What are the knowledge, skills, and attitudes that the graduating engineer should possess?" The groups' responses were charted.

We then organized results of the focus groups, plus the topics extracted from the aforementioned views of industry, government, and academia on the expectations a university graduates, into a preliminary draft syllabus, which contained the first four-level organization of the content.

The four top levels of our syllabus' content would map directly to our four major goals as stated: Educate students who understand how to conceive – design – implement – operate (Level 4 – CDIO) complex value – added engineering systems (Level 1 – Technical) in a modern team based engineering environment (Level 3 – Interpersonal) and are mature and thoughtful individuals (Level 2 – Personal).

This preliminary draft was reviewed through a survey of senior U.S. industry leaders, academic faculty, and alumni. The qualitative comments from this survey were incorporated, improving the syllabus's organization, clarity, and coverage.

Each second level (X.X) section of the syllabus was peer reviewed by experts. Combining the results of the peer review, and a check of additional sectional references, we completed the draft topical version of the syllabus.

To ensure comprehensiveness and to facilitate comparison, the contents of the syllabus were explicitly correlated with the comprehensive source documents.

We determined that the desired attributes of an engineering graduate include understanding of fundamentals, understanding of the design and manufacturing process, possession of multidisciplinary system perspective, good communications skills, and high ethical standards.

To translate our list of topics and skills into learning objectives, we needed a process to determine the level of proficiency expected of graduating engineers in each of the syllabus topics. This process needed to include stakeholder input and encourage consensus. This was achieved by conducting a well-formulated survey, conducting the surveys among appropriate stakeholder groups, and reflecting on the results.

Curricular Reform

In order to attain our learning goals, improvements must be made to our curricula. The challenge is to find innovative ways to make double duty of teaching time so that students develop a deeper working knowledge of the technical fundamentals while simultaneously learning CDIO skills. This requires changes in curricular structure, exploiting extracurricular and extra-campus learning opportunities, and development of new teaching materials.

Early in the CDIO curriculum, students are exposed to the engineering experience and given opportunities to build things.

We must *design* a new curriculum. This first requires benchmarking of the existing curriculum from the perspective of the CDIO syllabus. To improve on the identified shortcomings, three innovative curricular structures are envisioned. The first is an introduction to engineering experience, which motivates students to be engineers, exposes them to essential early skills and lets them build something. We call this the *cornerstone*. Conventional disciplinary subjects can be better coordinated and *linked* to demonstrate that engineering requires interdisciplinary efforts. Finally, the *capstone* is revised to include a substantial experience in which students design, build, and operate a product/system. With these new structures in place, a plan to overlay the CDIO syllabus skills can be developed. Encouraging and facilitating extracurricular learning in the form of student projects can significantly expand the time available for learning CDIO skills, and internships and co-ops can become more integrated designed extensions of the overall learning experience.

Teaching and Learning Reform

Having addressed the curricular issues of *what* we teach and *where* we teach, we must consider the pedagogic issues of *how* we teach and how students learn.

To understand the CDIO Initiative's pedagogical improvements, we must consider what we know about students' experience and its effect on learning. Engineering students tend to learn from the concrete to the abstract. Yet students no longer arrive at universities armed with hands-on experiences from tinkering with cars or building radios. They have little personal foundation of experience upon which to map the theory they will try to learn. To address this and other learning needs, the CDIO Initiative prescribes improvements in four basic areas: increase in active and hands-on learning, emphasis on problem formulation and solution, increased emphasis on concept learning, and enhancement of learning feedback mechanisms.

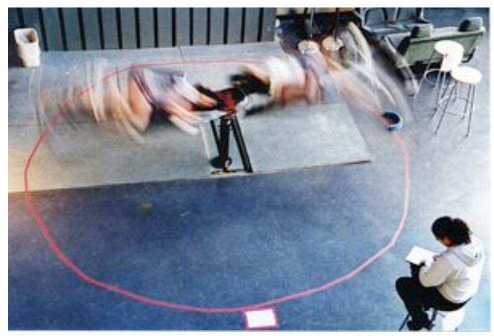
Educational research confirms that active learning techniques dramatically increase student learning. CDIO's emphasis on active learning encourages students to take more active roles in their own learning. Hands-on and team learning are important examples of active learning, but techniques can be used to increase student activity even in conventional class settings.

Solving problems is the essential skill of engineering. The CDIO Initiative supports learning in problem formulation, estimation, modeling and solution. Some teaching is organized in a modified problem based learning format, but always with strong emphasis on the fundamentals. A related effort in concept learning works to insure that students master the tools and techniques of engineering, as well as the deeper underlying concepts.

As an integral part of the active engagement process, teachers must probe learning against established learning objectives. Central to the CDIO Initiative are new ways of obtaining feedback; from electronic real-time classroom responses, to "between the lectures" response systems.

Workspaces and Laboratories

Engineers design and build products and systems. By providing students with repeated authentic design-build experiences, they develop and reinforce a deep working knowledge of the fundamentals, and learn the skills to design and develop new product/systems. In the CDIO Initiative, courses are developed that enhance this theory–to–practice learning. Experiences in conceiving, designing, implementing and operating are woven into the curriculum, particularly in the introductory cornerstone and concluding capstone. The capstone potentially expands into a multi-semester experience, more closely linked to disciplines, which results in students designing, building and operating a product. With theory development paralleling practical implementation, students learn both the applicability and limitations of theory.



Engineering learning environments must include spaces for students to operate their own experiments.

If our students are to understand that conceiving – designing – implementing – operating is the context of the education, then it is desirable that we build workspace/laboratories that are supportive of, and, in fact, are organized around C, D, I and O. Conceive spaces encourage interaction with humans to understand needs, and include both team and personal spaces to encourage reflections and conceptual development. They are largely technology-free zones. Facilities must be made available to introduce students to the modern paradigms of digitally enhanced collaborative design, and modern fabrication and integration of hardware and software. Operation is difficult to teach in an academic setting, but students can learn how to operate their experiments as well as faculty class experiments. Simulations of real operations, as well as electronic links to real operations environments supplement the direct student experience.

The workspace/laboratories must also support the other modes of active and hands-on learning, including experimentation, disciplinary laboratories and social interaction. The space must facilitate and encourage team building and team activities.

Assessment

CDIO is an improvement process requiring rigorous assessment that guides the educational reform process. The assessment element developed as part of the CDIO Initiative evaluates individual student learning and overall impact of the entire educational initiative.

Assessment is based on objectives. Examination confirms that many contemporary educational objectives are vague and relatively immeasurable. The CDIO Initiative's comprehensive practices are based on widely accepted educational taxonomies, guaranteeing clear and measurable assessment statements of each educational objective. The CDIO syllabus codifies nearly 80 identifiable attributes identified as important for graduating engineers. As it is impossible to actively assess each, procedures allow assessment for representative or aggregate sets of CDIO performance attributes. The fact that several universities have now implemented CDIO makes possible cross controls for unique pedagogical and curricular studies, and important programmatic comparisons.

CDIO adopts assessment tools, such as portfolios and design reviews, from other professions that embrace creativity, design and entrepreneurship. Students become more responsible not only for learning, but also for self and peer assessment. Attitudinal change as well as skill progression are assessed.

In addition to assessing pedagogical performance, the CDIO Initiative assesses efficiency of curricular change and acknowledges its impact on the steady state. Indeed, CDIO's integral assessment elements provide a comprehensive process that quantifies the program's effectiveness on a multitude of planes.

Benefits and Open Architecture

Through its concept, and associated reforms of curriculum and pedagogy, creation of workspaces, activities and assessment process, CDIO resolves the essential conflict in engineering education time for learning both the fundamentals and other important skills.

CDIO benefits the students, their future employers and our society. Students are better equipped to enter industry, and to design and build new products and systems of benefit to humankind, to the competitive advantage of their enterprise. To deliver this benefit, CDIO must impact educational programs and their students. CDIO is a generalizable approach to the reform of engineering education, and has been implemented in American and European universities' aerospace, mechanical, and electrical engineering; and applied physics programs.

CDIO is an open architecture endeavor. It is specifically designed for, and offered to, all university engineering programs to adapt to their specific needs. It is an ongoing development effort. Participating universities will develop materials and approaches to share with others. Many already have unique capabilities that could enrich other programs. Therefore, we are developing an open, accessible architecture for the program materials, for disseminating and exchanging resources.

The Collaborators

CDIO was conceived at the Massachusetts Institute of Technology in the late 1990s. In 2000, with funding from the Wallenberg Foundation, Chalmers Institute of Technology, Linköping University, and the Royal Institute of Technology (KTH), all of Sweden, collaborated with MIT to form the CDIO Initiative. Since that time, CDIO has grown to include 23 schools in the U.S., U.K., Europe, Asia, and the Pacific. Indeed, CDIO has become a worldwide venture. This growth allows Initiative collaborators to share to pool resources, share experiences, and adapt the CDIO syllabus to a variety of engineering disciplines. To better serve the growing CDIO community, the Initiative has organized regional CDIO groups. U. Pretoria is the CDIO Centre for Southern Africa; MIT is the Center for North America. The University of Liverpool and Queen's University of Belfast jointly run the UK-Ireland Centre. Chalmers, KTH, and Linköping oversee the Nordic Centre. In designing and administrating CDIO, we assembled a unique development team of curriculum, teaching and learning, assessment, design and build, and communication professionals. They are available to provide information and assist others who want to explore adopting CDIO in their institutions. There is a wealth of development material

CDIO collaborators from around the world meet regularly to pool their ideas.

available ranging from model surveys, to assessment tools, to reports from institutions that have implemented the CDIO Initiative.

To contact the CDIO team, email info@cdio.org or telephone the CDIO Communications Director at (617) 253-1564. For more information on the CDIO Initiative, visit http://www.cdio.org.

The CDIO syllabus (Condensed)

1 TECHNICAL KNOWLEDGE AND REASONING

- 1.1. KNOWLEDGE OF UNDERLYING SCIENCES
- 1.2. CORE ENGINEERING FUNDAMENTAL KNOWLEDGE
- 1.3. ADVANCED ENGINEERING FUNDAMENTAL KNOWLEDGE

2 PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES

- 2.1. ENGINEERING 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 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. Tradeoffs, Judgment and Balance in Resolution
- 2.4. PERSONAL SKILLS AND ATTITUDES
  - 2.4.1. Initiative and Willingness to Take Risks
  - 2.4.2. Perseverance and Flexibility
  - 2.4.3. Creative Thinking
  - 2.4.4. Critical Thinking
  - 2.4.5. Awareness of One's Personal Knowledge, Skills, and Attitudes
  - 2.4.6. Curiosity and Lifelong Learning
  - 2.4.7. Time and Resource Management
- 2.5. PROFESSIONAL SKILLS AND ATTITUDES
  - 2.5.1. Professional Ethics, Integrity, Responsibility and Accountability
  - 2.5.2. Professional Behavior
  - 2.5.3. Proactively Planning for One's Career
  - 2.5.4. Staying Current on World of Engineer

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. Leadership
  - 3.1.5. Technical Teaming
- 3.2. COMMUNICATION
  - 3.2.1. Communication Strategy
  - 3.2.2. Communication Structure
  - 3.2.3. Written Communication
  - 3.2.4. Electronic/Multimedia Communication
  - 3.2.5. Graphical Communication
  - 3.2.6. Oral Presentation and Interpersonal Communication
- 3.3. COMMUNICATION IN FOREIGN LANGUAGES
  - 3.3.1. English
  - 3.3.2. Languages within the European Union
  - 3.3.3. Languages outside the European Union

4 CONCEIVING, DESIGNING, IMPLEMENTING AND OPERATING SYSTEMS IN THE ENTERPRISE AND SOCIETAL CONTEXT

- 4.1. EXTERNAL AND SOCIETAL CONTEXT
  - 4.1.1. Roles and Responsibility of Engineers
  - 4.1.2. The Impact of Engineering on Society
  - 4.1.3. Society's Regulation of Engineering
  - 4.1.4. The Historical and Cultural Context
  - 4.1.5. Contemporary Issues and Values
  - 4.1.6. Developing a Global Perspective
- 4.2. ENTERPRISE AND BUSINESS CONTEXT
  - 4.2.1. Appreciating Different Enterprise Cultures
  - 4.2.2. Enterprise Strategy, Goals and Planning
  - 4.2.3. Technical Entrepreneurship
  - 4.2.4. Working Successfully in Organizations
- 4.3. CONCEIVING AND ENGINEERING SYSTEMS
  - 4.3.1. Setting System Goals and Requirements
  - 4.3.2. Defining Function, Concept and Architecture
  - 4.3.3. Modeling of System and Ensuring Goals Can Be Met
  - 4.3.4. Development Project Management
- 4.4. DESIGNING
  - 4.4.1. The Design Process
  - 4.4.2. The Design Process Phasing and Approaches
  - 4.4.3. Utilization of Knowledge in Design
  - 4.4.4. Disciplinary Design
  - 4.4.5. Multidisciplinary Design
  - 4.4.6. Multi-objective Design
- 4.5. IMPLEMENTING
  - 4.5.1. Designing the Implementation Process
  - 4.5.2. Hardware Manufacturing Process
  - 4.5.3. Software Implementing Process
  - 4.5.4. Hardware Software Integration
  - 4.5.5. Test, Verification, Validation and Certification
  - 4.5.6. Implementation Management
- 4.6. OPERATING
  - 4.6.1. Designing and Optimizing Operations
  - 4.6.2. Training and Operations
  - 4.6.3. Supporting the System Lifecycle
  - 4.6.4. System Improvement and Evolution
  - 4.6.5. Disposal and Life-End Issues
  - 4.6.6. Operations Management